HYBRID AIRCONDITIONING SYSTEM FOR INDIAN CLIMATIC CONDITIONS

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

By

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to the

DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

MARCH, 1989

CERTIFICATE

Certified that this work on "Hybrid Air Conditioning System for Indian Climatic Conditions" by Rajeev Khandelwal has been carried out under my supervision and has not been submitted elsewhere for degree.

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March'89

ACKNOWLEDGMENTS

Sincere thanks to Dr. Manohar Prasad are not enough for his guidance and ever willingness to discuss difficulties as and when they came up. His novel ideas and concepts helped me in shaping my attitude towards the subject and carrying out this modest piece of work.

I am also thankful to Mr. P.N. Mishra and Mr. Sushil Mishra, the technical staff of the refrigeration and air conditioning laboratory, for the help they provided in the fabrication of the system.

The helpful and encouraging attitude of my friends from H-Top, Hall 5, Arun Singhal, Arun Kumar, Chunnu, Lala, Nishith (dadiwala), Pankaj, Sanjay, Sripat, R.P. and V.P. who provided enthusiasm in periods of trouble and made my stay here memorable. I owe them a lot.

In particular, I am grateful to Manindra Agrawal (Doff) and Bansi who helped me in bringing this work to its final form.

-Rajeev

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NOMENCLATURE

A	Wall/ceiling surface area (m^2)
A_b	Area of body (m^2)
ADP	Apparatus dew point temperature (C)
C	The heat loss by convection from the outer surface of the clothed body (kW)
C_C	Cost of electricity
C_E	Effective cost of electricity
C_{I_a}	Initial cost of system A
C_{I_b}	Initial cost of system B
C_{I_d}	Initial cost of desert cooler
C_M	maintenance cost
C_T	Total cost
DPT	Dew point temperature (C)
ET	Effective temperature (C)
F	Multiplying factor for solar radiation
h	Enthalpy of moist air (kJ/kg of dry air)
IDT	Internal design temperature (C)
K'	Heat transfer from the skin to the outer surface of the clothed body (kJ)
L	Life period of airconditioner and hybrid system (years)
L'	Dry respiration heat loss (kW)
n_{ch}	Number of air changes/hour
OF	Operating factor (Fraction of the year)
P_v	Partial vapour pressure (bar)
P_{vs}	Saturation vapour pressure (bar)

Q'	Internal heat production in the human body (kW)
Q_m	Rate of heat generation within body (kW)
Q_d	Heat loss by water vapour diffusion through the skin (kW)
Q_{sw}	Heat loss by evaporation of sweat from the surface of the skin (kW)
Q_{re}	The latent respiration heat loss (kW)
$\dot{Q}$	Heat load (kW)
R	Rate of interest per annum
R'	The heat loss by radition from the surface of the clothed body
SF	Safety factor
SHF	Sensible heat factor
T_a	Ambient temperature (C)
T_i	Inside design temperature (C)
T_s	Surface temperature of the cooling coil (C)
$T_{[illegible]}$	Skin temperature (C)
T_{ds}	Dry bulb temperature (C)
T_{wb}	Wet bulb temperature (C)
T_d	Dew point temperature (C)
$\overline{T}_{sa}$	Average sol air temperature for the whole day (C)
$T_{sa-\tau}$	Sol air temperature τ hour before the time considered (C)
t_1	Dry bulb temperature of the leaving air (C)
t_2	Dry bulb temperature of the entry air (C)
t'	Thermodynamic wet bulb temperature of the entering air (C)
TR	Ton of refrigeration (3.5 kW per ton)
U	Overall heat transfer coefficient $kW/m^2.K$

V	Volume of ventilation and infiltration air (m^3)
v_a	Specific volume of air (m^3/kg)
V_{air}	Volume of circulated air (m^3/kg)
V_{room}	Volume of room (m^3)
W	Absolute humidity (kg/kg of dry air)
W_s	Absolute humidity at saturation
X	Bypass factor
β	Cost multiplication factor for desert cooler
ϕ	Relative humidity (%)
λ	Decrement factor
τ	Time lag factor (h)
η	Efficiency of desert cooler

ABSTRACT

Presently the comfort Airconditioning has become indispensible on account of better product and increased productivity requirements. However, the operating cost of the same is rather exorbitant due to high cost of energy. As such attempts have been made to use higher temperature and humidity conditions in order to decrease energy requirement for the same. In this context a climatic survey of India has been carried out for different parts of India with a view to assess the possibility of the use of economic and energy efficient systems.

The thermodynamic analysis based on the inside and outside design conditions established the need of both the evaporative cooling and the conventional airconditioning for the major part of the country to meet the comfort requirement during different seasons. These considerations brings out the need of a system which incorporates the features of both the desert cooler and the conventional airconditioner. A new system which we have developed has these two operations in one unit. It has been named as the 'hybrid airconditioner.'

The experimental results have been obtained for the above system. It takes about 1.4 kW and 250W respectively for 1 ton capacity when it operates in the conventional airconditioning and evaporative cooling modes. This development has opened a new area in the field of airconditioning for energy conservation.

CHAPTER 1

INTRODUCTION

1.1 NEED FOR AIR CONDITIONING

Air conditioning is constantly absorbing the latest developments of science and technology in order to meet the environmental requirements of both man and machine. The term air conditioning stands for the simultaneous control of temperature, humidity, purity and movement. Air conditioning can be classified as comfort and industrial. The former deals with human comfort which also requires noise control while the latter is meant for industrial products or commodities, production centres, laboratories, cold-storages, instrumentation etc. Today it plays a significant role in modern lives.

1.2 CONCEPT OF COMFORT

Human-beings are warm blooded animal and hence have an essentially constant internal body temperature despite the different thermal environment to which they are exposed. The first requirement for thermal comfort under steady state conditions is that the heat balance equation of human body as a control volume is satisfied, i.e.,

$$Q' - Q_d - Q_{sw} - Q_{re} - L' = K' = R' + C \qquad (1.1)$$

where,

Q' = Internal heat production in the human body.

Q_d = The heat loss by water vapour diffusion through the skin.

Q_{sw} = The loss by evaporation of sweat from the surface of the skin.

Q_{re} = The latent respiration heat loss.

L' = The dry respiration heat loss.

K' = The heat transfer from the skin to the outer surface of the clothed body.

R' = The heat loss by radiation from the surface of the clothed body.

C = The heat loss by convection from the outer surface of the clothed body.

This requirement is an expression for the purpose of man's thermo-regulatory system; to maintain a reasonably constant internal body temperature.

For a given activity level, the skin temperature T_s and the sweat secretion Q_{sw} are seen to be the only physiological variables influencing the heat balance for human comfort. For a given person with a given activity level, clothing and environment, a certain combination of T_s and Q_{sw} will arise so that the heat balance equation is satisfied. Human thermo-regulatory system is quite versatile

and the heat balance can be obtained within wide limits of environmental variables, corresponding to wide limits of physiological parameters.

"Satisfaction of heat balance equation(1) is a necessary but not a sufficient condition for thermal comfort." Within the wide range of environmental variables for which a heat balance will be maintained, there is only a narrow zone which will create thermal comfort. Corresponding to this is a narrow range of mean skin temperature and sweat secretion .

Fanger [1] found that for constant comfort, the mean skin temperature decreases with increasing activity (for Q_m/A_b= 210 kJ/h-m^2, T_s is 34 C, for Q_m/A_b= 630 KJ/h-m^2, T_s is 31 C).

The sweat secretion at thermal comfort is zero for sedentary activity level (Q_m/A_b= 210 kJ/h-m^2). At higher activities moderate sweat secretion is necessary for thermal comfort. If the environment is so cold that sweat secretion is completely suppressed at higher activity than the person would feel discomfort.

1.3 COMFORT REQUIREMENT AND ENERGY CONSTRAINT

The requirement of comfort air conditioning is increasing extensively due to emphasis on enhanced produc-

tivity and better quality. On the other hand the cost for air conditioning is a limiting factor due the energy crisis. There is a growing concern among the engineers and scientists all around the world to save energy. Thus a compromise between energy requirement and comfort level has been found in [2]. For comfort inside design conditions as high as T_{db}= 30 C and Ø = 60% have been suggested for average activity of man. The higher value than the existing data has been supported by Whitner [3] and ASHARE comfort chart value [4]. Of course the air velocity has been enhanced to 0.7 m/s or higher as against the near static air velocity of 0.13 m/s used presently for comfort air conditioning. In India Malhotra [5] has obtained the effective temperature for hot and humid as well as hot and dry climate based on recording of votes. The comfort zones found by him are given in Table 1.1

<u>Table 1.1</u>

Comfort conditions for hot and humid as well as hot and dry climates [5]

S.No.	Level of comfort	Effective Temperature, ET, in C	
		Hot and humid climate	Hot and dry climate
1.	Warm & unpleasant	27.0	26.7 - 28.3
2.	Comfortable & pleasant (Upper level)	24.5 -25.0	24.4 - 26.6
3.	Comfortable & pleasant (Lower level)	22.0 - 22.5	21.1 -24.3

As it has been found that the energy requirement to cause circulation of air is far less than that required for lowering the temperature. The extensive work done by Tanabe and Kimura [6] has found T_{db}=30 C and Ø = 60% to be reasonably comfortable condition at air velocities of 0.7m/s as predicted by Prasad [7].

Table 1.2

Comfort conditions for human comfort in the light of energy conservation [6]

S.No.	Experimental Condition	Air motion (m/s)
1.	27 C, Ø = 50%	0.5
2.	29 C, Ø = 50%	1.2
3.	31 C, Ø = 50%	1.6

Using the concept of using higher air velocities for comfort at lower energy cost 'Spot-cooling' systems have been designed,for example, in industry, air crafts, offices, etc., as mentioned by Olsen and Nielsen [8]

1.4 CONCEPT OF HYBRID SYSTEM

In India the climatic conditions are varying both with time and place. However, the inland areas experiences three set of representative conditions corresponding to summer, rainy and winter seasons. It has been found after extensive study that cooling is required for summer and rainy season but not for winter season. If the inside comfort conditions are taken to be T_{db}= 25 C and Ø = 50%

and the representative outdoor conditions to be T_{db}= 41.1 C, Ø = 16% and T_{db}= 33.9 C, Ø = 78.7% respectively for summer and rainy season [Appendix A] then it is found that during summer the required process to achieve comfort condition is cooling and humidification and for rainy season the conventional cooling and dehumidification processes serve the purpose. These state points and processes have been marked on the psychrometric chart, Fig. 1.1.

The conventional window air conditioning unit acts as a cooling and dehumidification device and hence meets the requirement of rainy season. The desert coolers using adiabatic evaporation process are found to be very effective in summer season even though not a complete substitute for the conventional air conditioner.

There are two ways to achieve cooling

(a) Mechanical cooling

(b) Evaporative cooling

1.4.1 MECHANICAL COOLING : It can be achieved either by vapour-compression, absorbtion refrigeration, thermo-electric refrigeration or air-refrigeration. In this process a cooled media is generated by either of the above

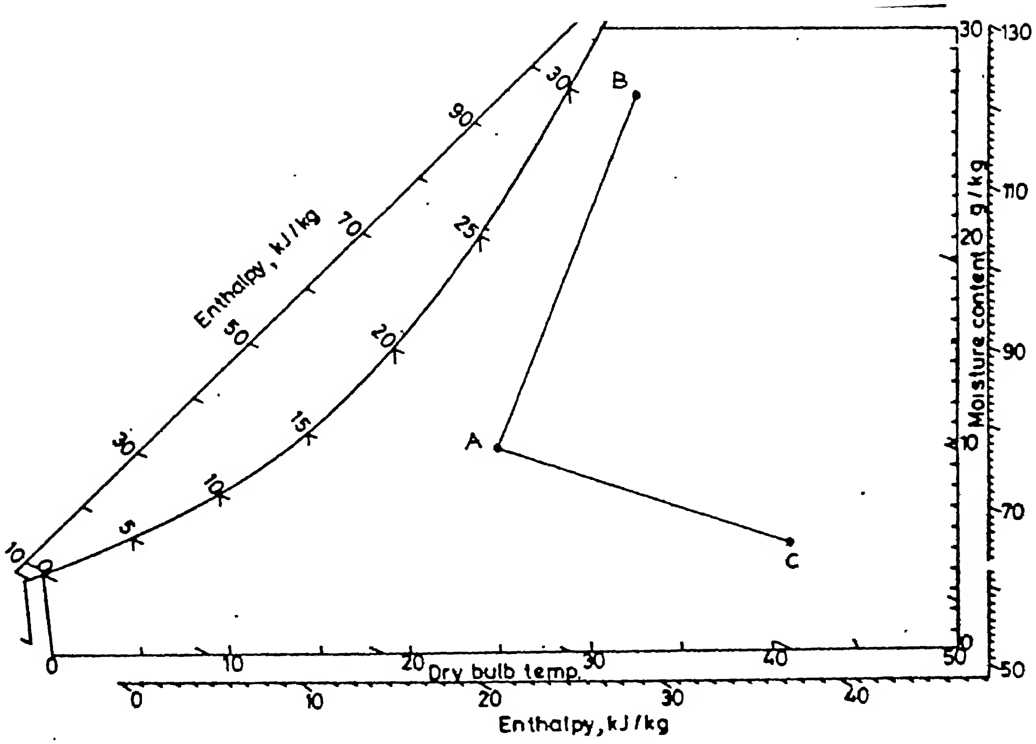


Fig. 1.1 Thermodynamic processes required for summer and rainy seasons

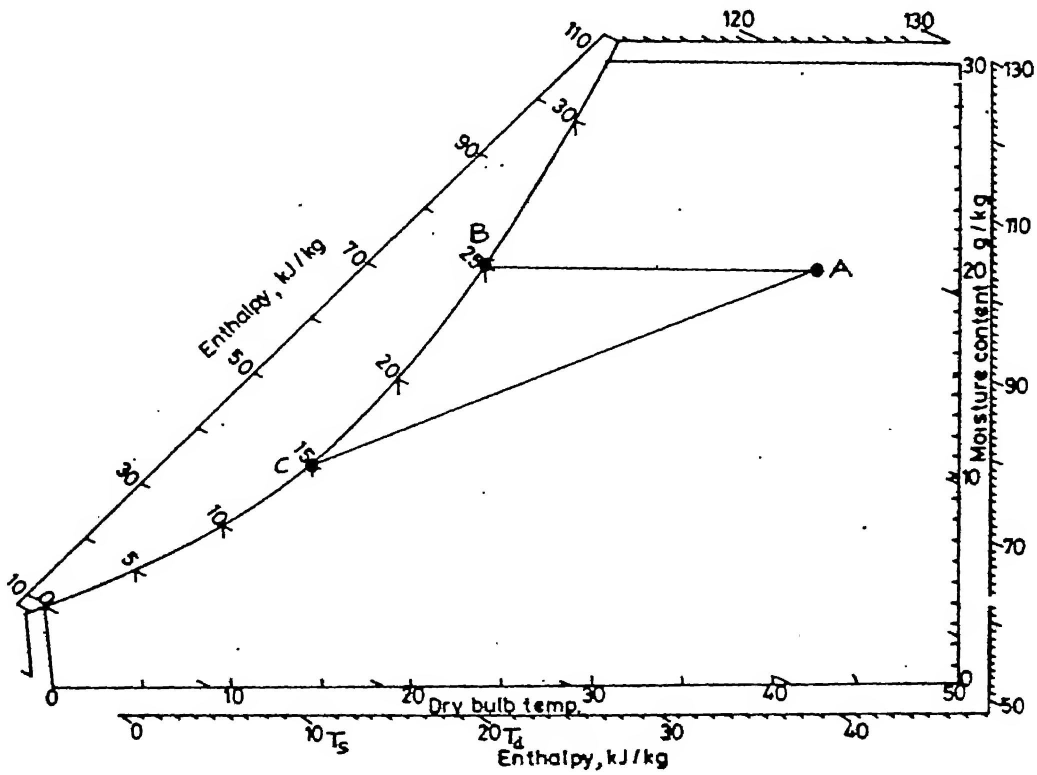


Fig. 1.2 Processes achieved by mechanical cooling

mentioned methods. It absorbs the heat from the surroundings. The process can be represented on the psychrometric chart (Fig. 1.2) by the process line AB or by line AC if the apparatus dew point, ADP, is lower than the dew point temperature of air to be conditioned. Thus we see that process AC represents a cooling and dehumidification process suitable for the rainy season.

1.4.2 EVAPORATIVE COOLING: The adiabatic evaporation of liquid leads to the drop in its temperature as the latent heat of vaporization is extracted from the fluid itself. The air in contact with such fluid gets cooled firstly due to heat transfer to the fluid and secondly due to the heat transfer as the latent heat. However, in such process the humidity of the air also gets increased. Thus in the adiabatic evaporation leads to cooling and humidification which is the requirement for the summer season. The lower limit of the temperature which can be achieved by this process is, however, limited by the wet-bulb temperature of the air to be processed. Also, higher humidity creates discomfort hence the high humidity renders it ineffective in the rainy season. Thus despite the lower power consumption in evaporative cooling one has to opt for the conventional air-conditioning system to meet the comfort requirement in rainy season.

To meet the different requirements and to overcome the inadequacy of any single prevalent system, viz.,air conditioner and desert cooler, it was decided to design and develop a system which incorporates the features of both of them. Such a system has been named as"Hybrid System". In marketing terminology it can be called a "two-in-one". The hybrid system has a uniquely designed condenser, viz., evaporative condenser which can perform either as evaporative cooler or as evaporative condenser depending on the requirement. This hybrid system performs as a desert cooler to achieve the comfort conditions. If the satisfactory conditions can not, however, be achieved due to higher humidity , the system manipulates to work as an air conditioner with better COP compared to the conventional air conditioning units with air-cooled condensers.

1.5 FEASIBILITY OF THE SYSTEM

1.5.1 THERMODYNAMIC FEASIBILITY: Due to the different thermodynamic processes required to meet the comfort conditions during the summer and the rainy season, in most of the inland areas of India, as detailed in the following chapters, it was found that both evaporative cooling and mechanical cooling are required. The requisite processes

are shown in fig. 1.1. Thus a hybrid system that can provide both cooling and dehumidification as well as cooling and humidification processes is thermodynamically feasible.

1.5.2 ECONOMIC FEASIBILITY: After establishing the thermodynamic feasibility of the system the system was checked for economic feasibility using Present Worth Method. Several authors [9,10,11] have studied the economic feasibility of the system extensively and found that despite higher intial cost as compared to conventional systems it works out to be cheaper due to drastic decrease in the operating cost on account of lesser electricity consumption. Thus system was found to be economically feasible as well.

1.5.3 PHYSICAL FEASIBILITY: Since the system was found to be both thermodynamically and economically feasible, the actual designing and fabrication was undertaken. The developed system was found to be physically feasible. Despite the shortcomings which are inevitable in the developmental stage of any new product, the system performed quite satisfactorily.

1.5.4 SOCIAL FEASIBILTY: The hybrid system presently

developed is bulkier than the existing models. Also the public is accustomed to the more convenient units which do not have the problems associated with water handling. However in light of the severe power constraint and energy crisis the hybrid system shall find social acceptibility in its latter developments which would be more compact and handy.

CHAPTER 2

CLIMATE OF INDIA

2.1 INTRODUCTION

India, our home land, is a country of great geographical extent. The land stretches on all sides encompassing the vast expanses of the northern plains, the thirsty sand of the Thar on the west, the intricate maze of Assam hill and vales on the east, the ancient hills and coconut bearing coastal plains on the south, and the lofty, snowcapped mountains on the north. The land gets and abundance of sunshine from the tropical sun and the splashing rains from the monsoons - the two elements together exerting a tremendous impact on the destiny of its teeming millions.

2.2 CLIMATIC VARIATIONS

If the climate of India is to be described just in one word, it is 'Monsoon'. The broad unity of the Monsoon Type of climate should not, however, lead as to ignore the regional variations in the climatic characteristics which so strikingly differentiate the climate of Kerala and Tamil Nadu from that of Uttar Pradesh and Bihar. Not withstanding its broad unity, the climate of India has

many regional variations expressed in the pattern of winds, temperature, and rainfall, rhythm of seasons and the degree of wetness or dryness. These differences in the climatic characteristics are determined by location, altitude, distance from the sea or the mountains and the general relief. These diversities are only regional facets or sub-types of an overall monsoon climate.

Let us have a closer look at these regional variations in temperature, winds and rainfall patterns. Barmer in Rajasthan may record a temperature of 48 C or 50 C on a June day, while the mercury hardly touches 22 C at Gulmarg or Pahalgam in Kashmir on the same day. On a December night, Dras or Kargil shivers with freezing cold - the minimum temperature being as low as -40 C while Trivandrum or Madras record only 20 C or 22 C. These differences are equally striking in rainfall patterns also - Cherapunji receives 1080 cm over the years, while the annual total hardly exceeds 12 cm at Jaisalmer[14]

The people of Bombay and the Konkan coastal lands have hardly any idea of the extremes of the temperature and the seasonal rhythm of the weather. On the other hand, the seasonal contrasts in weather at places in the interior of the country, such at Kanpur, affect the entire cycle of activity in all spheres of life.

Similarly, there are differences in the onset and the withdrawal of the summer rains in different parts of the country. Places like Goa, Hyderabad, Bhubneshwar and Patna get rains by the first quarter of June while the rains might shill be eagerly awaited at Kanpur, Delhi and Chandigarh.

2.3 SEASONS IN INDIA

The meteorologists usually recognize the following seasons.[12]

1. The Cold weather season
2. The Hot weather season
3. The South-Western Monsoon Season
4. The season of Retreating Monsoon

2.3.1 COLD WEATHER SEASON: Usually the cold weather season begins with mid-November in Northern India, December and January are the coldest months. The mean daily temperature remains below 21 C over most of Northern India. The night temperature may be quiet low, often going below the freezing point. The rainfall decreases from north and north-west to the east. The average rainfall during the three months of December, January and February at Delhi is only 53 mm, in the plain between 18 and 25 mm. The north-eastern parts of India also gets rainfall during the

winter months. Arunanchal and Assam may get as much as 50 mm of rainfall during these months.

The peninsular regions of India, however, do not have any well defined cold weather season. There is hardly any seasonal change in the distribution pattern of temperature in coastal areas. The mean maximum temperature for the month of January at Trivandrum is as high as 31 C. The corresponding temperature for the month of June is 32.5 C. The east coast of India in the Tamilnadu comes under the influence of the northeast monsoon, which causes widespread rainfall in coastal areas [Map 2.1].

2.3.2 HOT WEATHER SEASON: The north Indian region experience a well defined hot weather season during the months of April, May and June. Temperature starts rising by the middle of March and by mid-May the mercury may touch 41 C to 42 C. The heat of the day is, however, generally reduced by the locally formed dust storm. Another striking feature of the hot weather season is the "loo", which are strong hot winds blowing during daytime over northern and north-western India. The mean daily monthly, temperature for the month of May at Delhi is as high as 41 C. The mean daily minimum temperature during the summer months also remains quite high and seldom goes

below 26 C. There are, however, variations in the pattern of the day temperature from region to region. The southern parts of India do not experience hot weather season as such [Map 2.2].

2.3.3 THE SEASON OF RAINS: The inflow of south-westerly monsoon into India brings about a total change in weather. The monsoon may burst in the first week of June or even earlier in the coastal areas, while in the interior it may be delayed up to first week of July. The day temperature register a decline of 5 C to 8 C, between mid-June and mid-July.

The Indian sub-continent receives bulk of its rainfall during the south-west monsoon period. The Arabian sea current causes rainfall over the west coast, Western ghats, Maharashtra, Gujarat, and parts of Madhya Pradesh. It merges with the Bay of Bengal coast over the Punjab and adjoining Himalayas. The Bay of Bengal current, on the other hand, strikes at the Bengal coast and the Southern face of the Shillong plateau. It is however, deflected towards the west and north-west moving over the northern plain parallel to the axis of Himalayas. The monsoon rainfall is characterized by a declining trend with increasing distance from sea; Calcutta receives 119 cm during the south-west monsoon period; Patna 105 cm;

Allahabad 76 cm; and Delhi 56 cm [Map 2.3].

The eastern coast of India particularly in Tamilnadu remains relatively dry during the south-west monsoon period. This is because the Tamilnadu coast lies in the rainshadow area of the Arabian sea current and is parallel to the Bay of Bengal current.

2.3.4 THE SEASON OF RETREATING MONSOON: The south-west monsoon begins to retreat from the northern India by the second week of September. Unlike the sudden burst, the retreat is highly gradual. The patterns of retreat also shows interesting regional variations. The weather during the season is characterized by high day temperatures, but nights are pleasant with the mean temperatures going to 20 C or even lower. The diurnal range of temperature is however more pronounced. During this season severe cyclonic storms develop in the Bay of Bengal, which moves in a south-easterly to north-westerly direction. They give substantial amount of rainfall on the eastern coast [Map 2.4].

2.4 CLASSIFICATION OF CLIMATES

The classification of climates into homogeneous types and sub-types is a complex exercise. The observed values

of various elements of climate such as temperature and rainfall have to be grouped together with the help of statistical procedure into a simple index. Generally the two most important climatic factors, considered in all schemes of climatic classification, are temperature and rainfall.

2.4.1 KOEPPEN'S REGIONS: Koeppen's method is based on the monthly values of temperature and precipitation. Koeppen identified five major climatic types. They are as follows: tropical climates; dry climates; warm climates; snow climates and ice climates. He used letter symbols – as A,B,C,D and E – to denote these climatic types. These five types can further be sub-divided into sub-types on the basis of seasonal variations in the distribution pattern of rainfall and temperature. For relationship between the major categories of climate and their subdivisions see appendix B. [13,16,17]

Based on Koeppen's method, India can be divided into the following climatic regions [Map 2.5].

1. Monsoon Type with short dry season (Amw)
2. Monsoon Type with dry season in high sun period (As)
3. Tropical Savannah Type (Aw)
4. Semi-arid steppe climate (BShw)
5. Hot desert Type (BWhw)

6. Monsoon Type with dry winters (Cwg)

7. Cold humid winters type with shorter summers (Dfc)

8. Polar Type (E)

Koeppen's Amw type of climate prevails over the western coast of India south of Goa. The As type, characterized by dry summers, is experienced along the Coromendel coast. The dry climate prevails in two parts of India. The interior peninsula, Rajasthan and parts of Haryana have Bshw type of climate while the extreme western Rajasthan is characterized by BWhw type of climate. Most of the peninsular plateau has tropical savannah type of climate (Aw). The plain of India falls under the warm temperature type of climate with dry winters (Cwg). The north-eastern India falls under Dfc type of climate. Here winters are cold and humid while the summers are short. Kashmir and the adjoining mountain ranges have a polar type of climate (E).

The utility of the above information for the selection of the air conditioning system is given in the subsequent chapter.

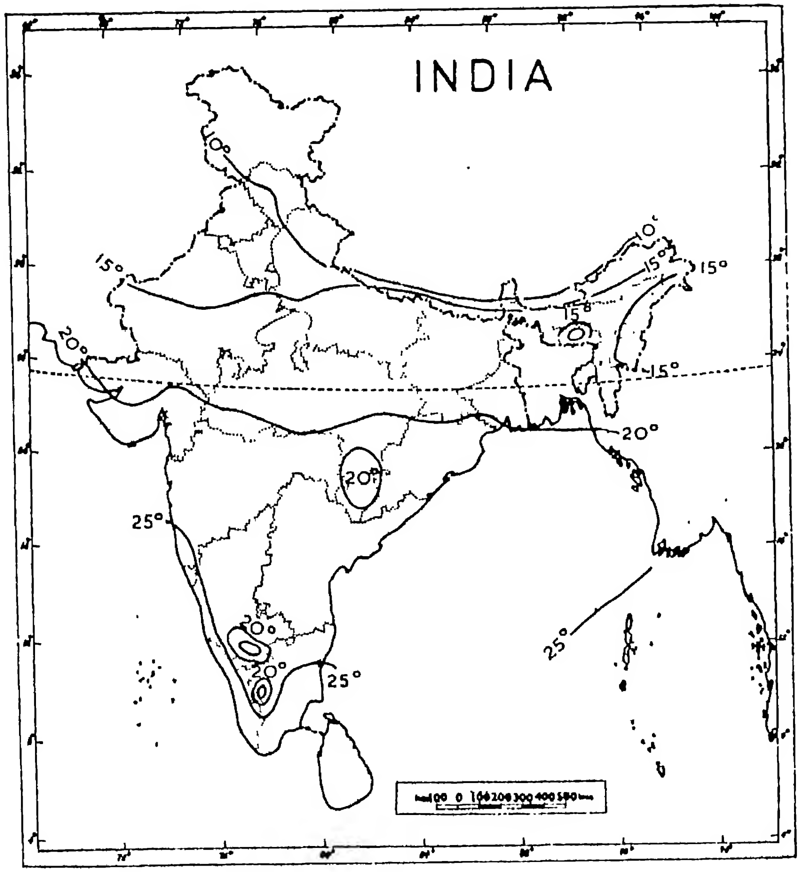


Fig. 2.1 Mean temperature (C) (January)

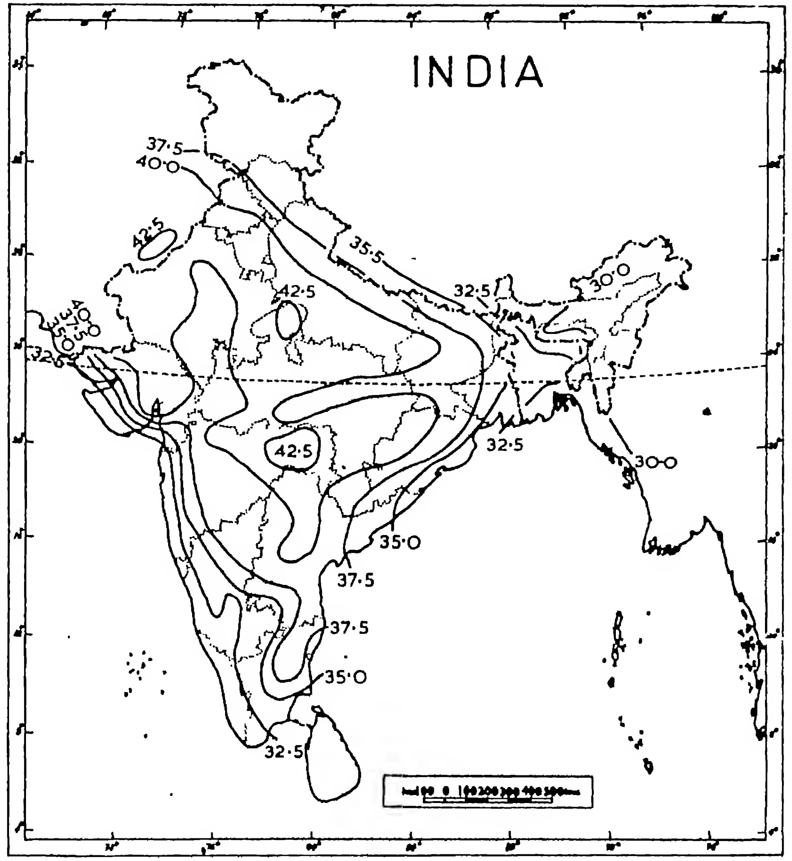


Fig. 2.2 Mean maximum temperature (C) (May)

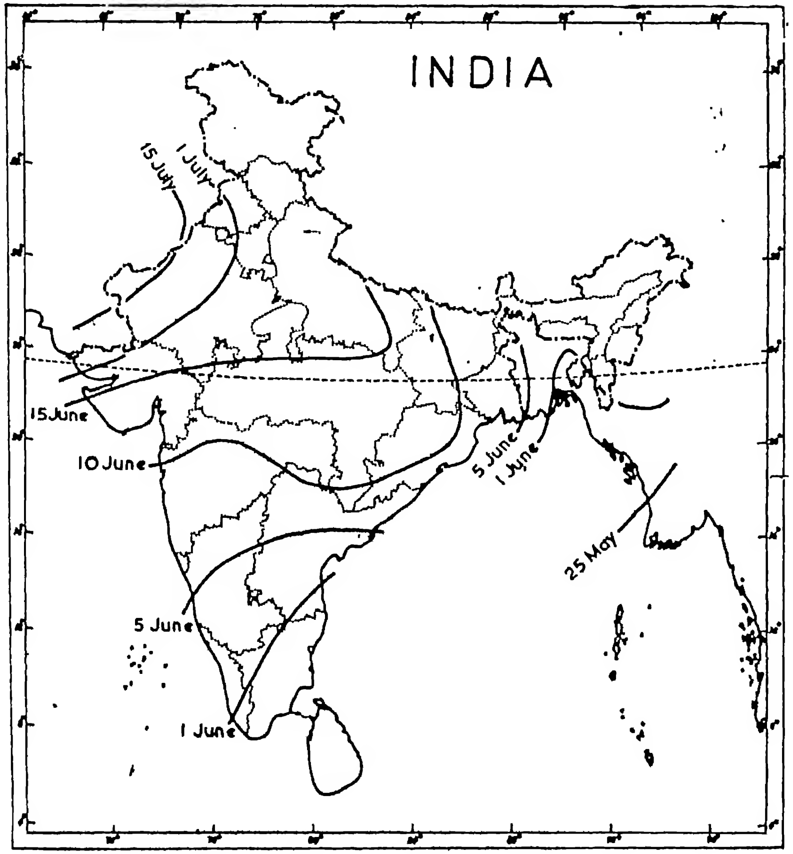


Fig. 2.3 Onset of south-west monsoon

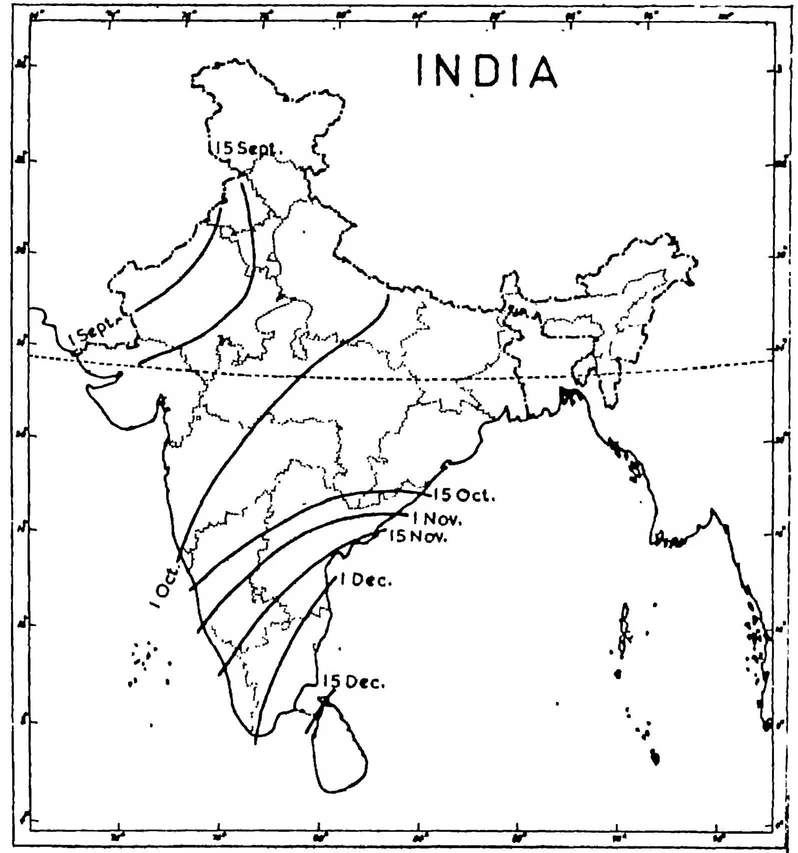


Fig. 2.4 Withdrawal of south-west monsoon

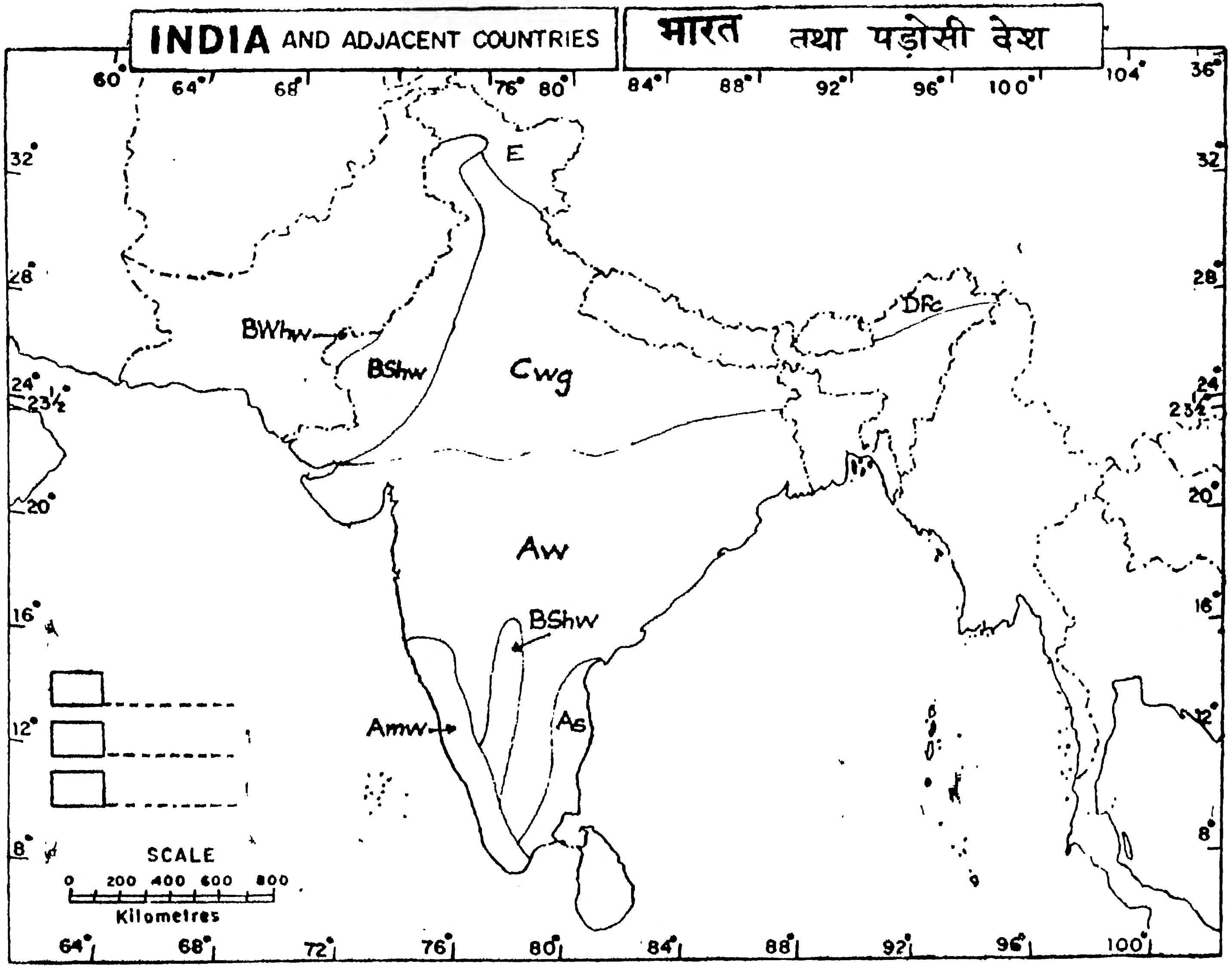


Fig. 2.5 Koeppen's climatic classification of India

CHAPTER 3

COMFORT AIR-CONDITIONING FOR INDIA

3.1 INTRODUCTION

In the last chapter we have briefly viewed the climatic pattern of India. We find that for comfort air conditioning there are different requirements at different places. The comfort conditions can be achieved by conditioning of air. The eight basic thermodynamic processes by which the state of moist air can be altered are shown in Fig. 3.1. They are :

(a) Sensible heating-process OA

(b) Sensible cooling-process OB

(c) Humidifying-process OC

(d) Dehumidifying-process OD

(e) Heating and humidifying-process OE

(f) Cooling and dehumidifying-process OF

(g) Cooling and humidification-process OG

(h) Heating and dehumidification-process OH

3.2 PROCESS REQUIREMENTS FOR DIFFERENT CLIMATIC ZONES

In monsoon type with short dry season (Amw) regions, the temperatures and humidities are usually high throughout the year. Hence, to achieve comfort conditions, we need cooling and dehumidifying process. In such regions

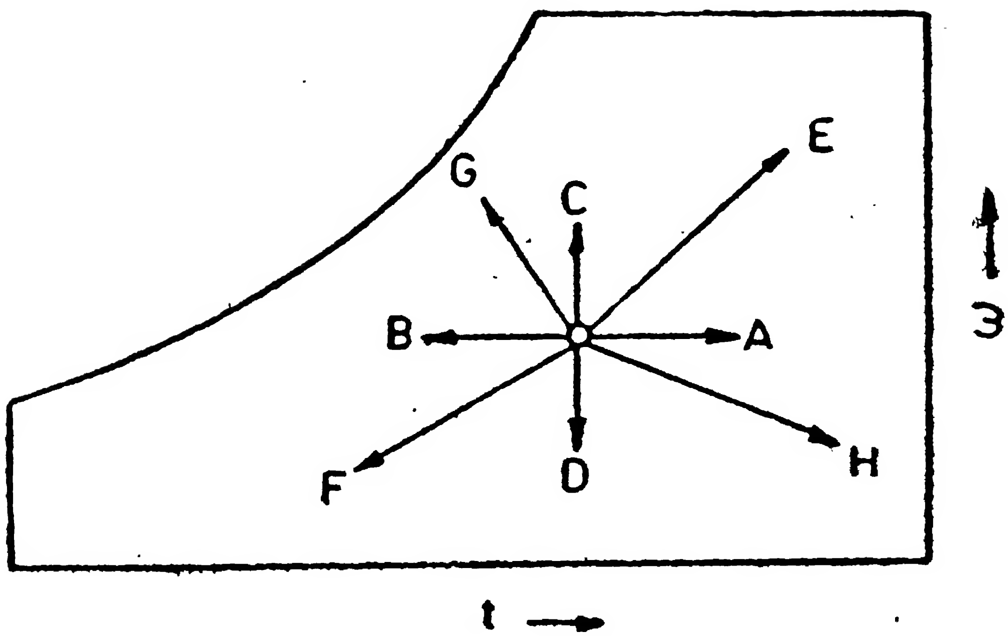


Fig. 3.1 Basic psychrometric processes

evaporative cooling is ineffective for most of the part of the year.

In the regions having monsoon type with dry season in high sun period (As) the temperatures are usually high but the humidity is low during high sun period. Thus, the comfort conditions can be achieved by evaporative cooling for some part of the year. However, for the remaining period it is essential to use cooling and dehumidification process.

The tropical savannah type (Aw) regions have great heat in summer. It constitutes the largest climatic region of India. The average monthly temperature during the dry season ranges between 22 C to 37 C. There is a general lowering of temperature during rainy season when the temperature ranges between 21 C to 26 C. The temperatures are quite high even during the winter season. Hence, in such regions the cooling and humidification process is essential for most of the time except during rainy season when the temperatures are moderate.

The regions experiencing semi-arid steppe climate (BShw) and hot desert type climate (BWhw) have two marked seasons : The summer and the winter season. Cooling and humidifying process is required for the summer season since these regions invariably have dry atmospheric

conditions. For the winter season, the required process for comfort air conditioning is heating and humidification.

The most important climatic region of India experiences monsoon type with dry winters (Cwg). The region comprises the plains of the Ganga which is one of the most populous regions of India. This region experiences the extremes of the climate. There are three well defined seasons, viz., summer, rainy and winter. During the summer season, the temperatures are very high and the humidity is low. The rainy season has high temperature and high humidity and the winters have low temperature. The thermodynamic processes required to condition air for comfort are different for the three seasons. For summer, the required process is cooling and humidification. For winter, it is heating and humidification whereas for rainy season, it is cooling and dehumidification.

The north-eastern India falls under Dfc type of climate. Here, the winters are cold and humid while the summers are short. For this region, heating is required for winters and cooling and dehumidification for the summers.

The smallest climatic zone of India, comprising of

Kashmir and the adjoining mountain ranges, has polar type of climate. Such regions invariably require heating to achieve comfort conditions even when the rest of India is shimmering under the hot sun.

Thus, we see that for most of the India, different processes are required at any place during different seasons. It has been found that evaporative cooling process is much less energy consuming than the mechanical cooling process. Since India is at present energy starved it comes as a great relief to know that in the major part of India evaporative cooling suffices for the summers when the energy scarcity is maximum. However, leaving aside the regions experiencing BShw and BWhw type of climates cooling and dehumidification of the ambient air is required during rainy season. The above study also reveals the need for heating process in the winters in all of India except the peninsular region. The average temperature, humidity and the rainfall for some of the representative stations of India is given in appendix C.

In the present work we shall limit ourselves to the region experiencing Cwg type of climate. As mentioned before, it is most populous and important climatic region. Kanpur has been taken as a representative station to design an ideal air conditioning system for this region.

The present practice in the region is to either use a window air conditioner or a desert cooler to achieve comfort conditions. During winters the normal practice is to use electric heaters.

3.3 WINDOW AIR CONDITIONER

Its major constituents are an evaporator, a condenser, a compressor and a throttling valve/capillary tube. It runs on electricity and cools the air of the conditioned space in the evaporator. The electric consumption is about 1.5 kW per ton of refrigeration. Most of the window air conditioners do not have any facility for heating of the conditioned space. From air conditioning point of view, it is the evaporator which is of major interest.

Moist air is passed over the cooling coils of the evaporator. Sensible or simple cooling of air takes place when air flows over the cooling coils whose surface temperature, T_s, is lower than the dry bulb temperature of the air as shown in Fig. 3.2. The air is cooled along the constant DPT line. The leaving air state depends on the bypass factor of the coil. Thus in Fig. 3.2, the leaving air state is 2 for the bypass factor of X. The bypass factor can be decreased and the leaving air state can be

made to approach the cooling coil surface temperature by increasing the number of rows in the coil. There is a minimum limit to the coil temperature for simple cooling, viz., T_d which is equal to the dew point temperature of the entering air.

Dehumidification will take place along with cooling if moist air flows over a cooling coil whose mean surface temperature, T_s, is below the dew point temperature, T_d, of the entering air as shown in Fig. 3.3. Between the air and the surface, both sensible and latent heat transfers will take place. For sensible heat transfer, the driving potential is the temperature differential $(T-T_s)$. For latent heat transfer, the driving potential is the partial pressure difference (P_v-P_{vs}) or the corresponding specific humidity difference $(W-W_s)$, where P_{vs} is the partial pres sure of water vapour in the air in the immediate vicinity of the cold surface at temperature T_s. The actual path followed in the process will be curve 1-S depending upon the heat and mass transfer coefficients. We shall assume this path to be a straight line 1-S. The leaving air state will, then, be at 2 as a result of the bypass factor of the coil.

There is, however, a limitation to the practical limit of this process. This limit is upto the condition

line 1-S' in Fig. 3.3, where it becomes a tangent to the saturation line. A sensible heat factor lower than that of the line 1-S' can not be achieved in any conditioning process with the given entering air state at 1. Even for the process 1-S', a very low value of the cooling surface temperature $T_{S'}$ would be required, resulting in a very low coefficient of performance of the refrigeration unit. Such a situation arises when the latent heat load is high and the SHF line is steep [18].

3.4 DESERT COOLER

The desert cooler consists of wetted pads through which air is passed which gets cooled and humidified by evaporative cooling. The evaporative cooling principle applies to all equipment that exchanges sensible heat for latent heat.

Evaporative air cooling utilizes the process of evaporating water into an air stream. Fig. 3.4 illustrates thermodynamic change that can take place between the air and the water that are in direct contact in the moving air stream. The continuously recirculated water achieves an equilibrium temperature equal to that of the entering air wet-bulb temperature. The heat and mass transfer process between the air and water lowers the air dry-bulb

temperature and increases the humidity ratio at constant wet-bulb temperature line as shown in Fig. 3.5.

The extent to which the leaving air temperature approaches the thermodynamic wet-bulb temperature of the entering air, or the extent to which complete saturation is approached, is conveniently expressed as 'cooling or saturation efficiency' and is defined as

$$\eta = \frac{t_2 - t_1}{t_2 - t'} \tag{3.1}$$

where,

η = cooling or saturation efficiency

t_2 = dry bulb temperature of the entering air

t_1 = dry bulb temperature of the leaving air

t' = thermodynamic wet-bulb temperature of the entering air

There are, however, limitations to the direct evaporative cooling process when the water bath is neither externally cooled nor heated. The first limit is thermodynamic. The lowest achievable temperature is limited by the wet-bulb temperature of ambient air. The second limit is due to the comfort requirement. In practice the saturation efficiency is maintained between 75-80% since at higher efficiencies the humidity becomes too high for comfort.

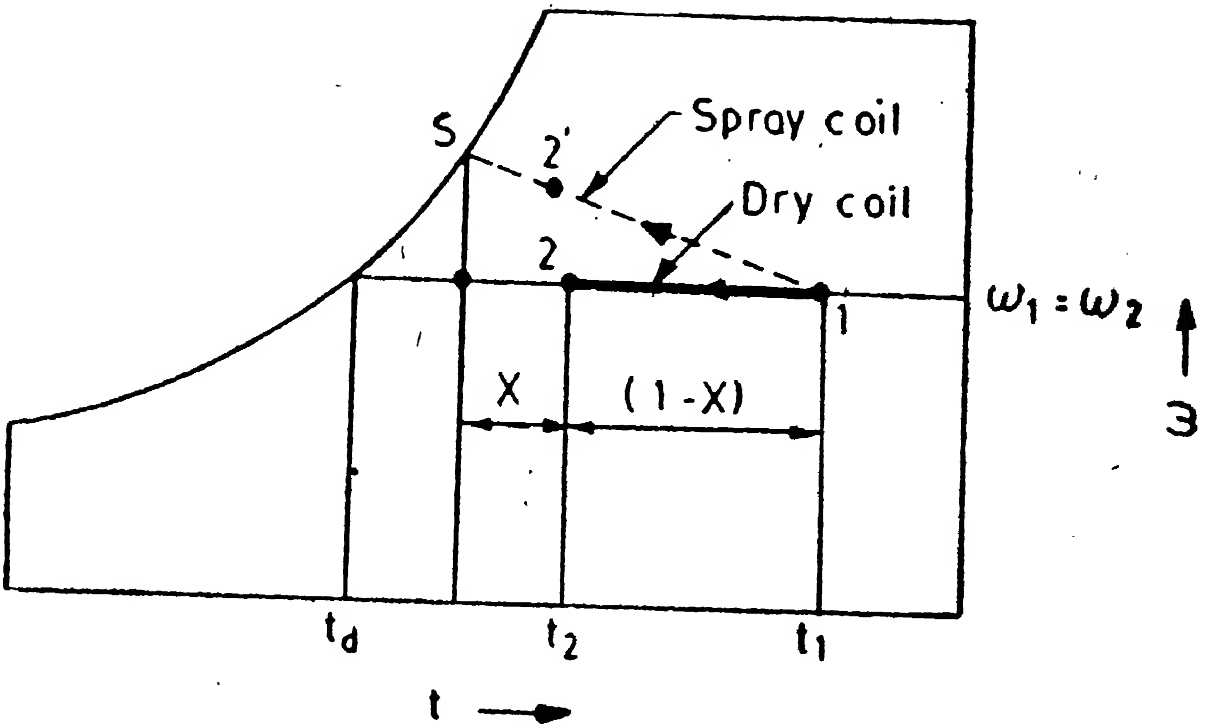


Fig. 3.2 Simple cooling

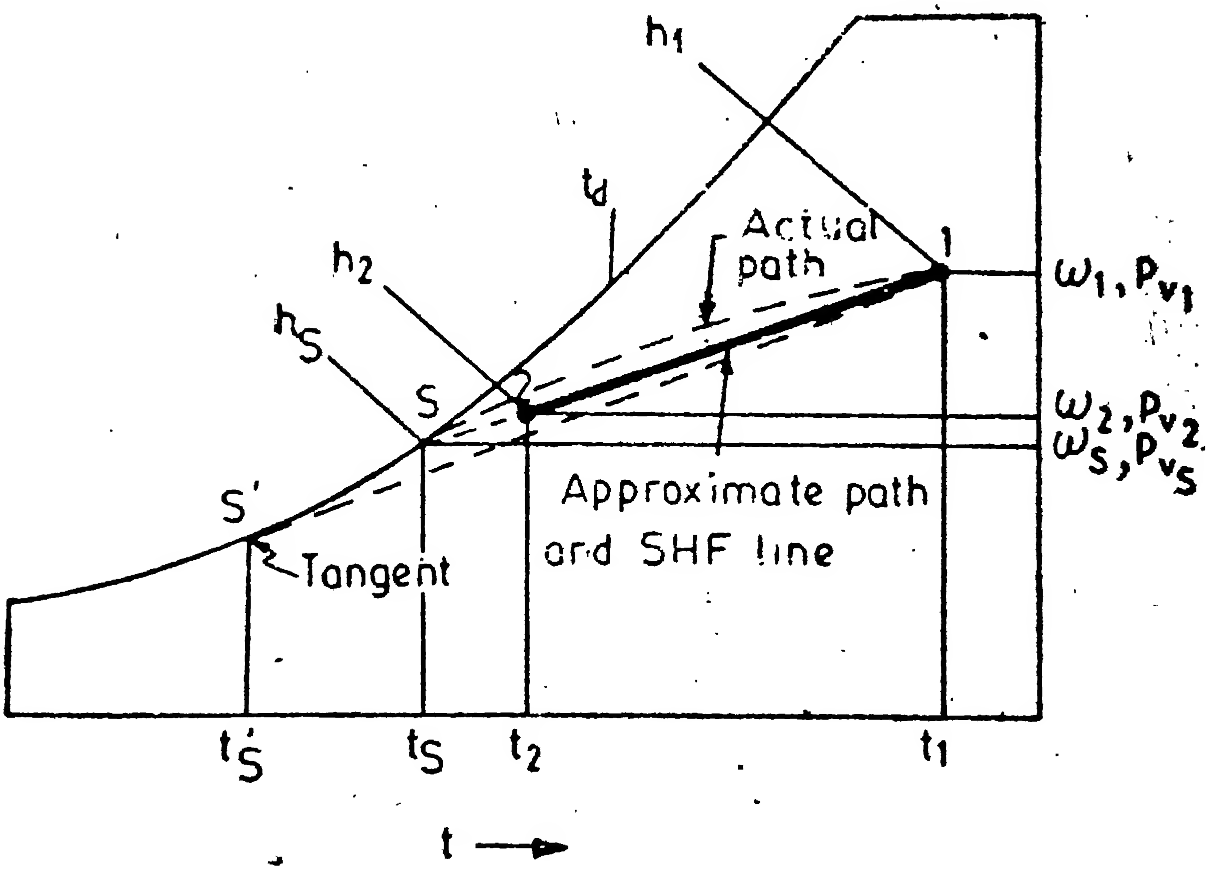


Fig. 3.3 Cooling and dehumidification

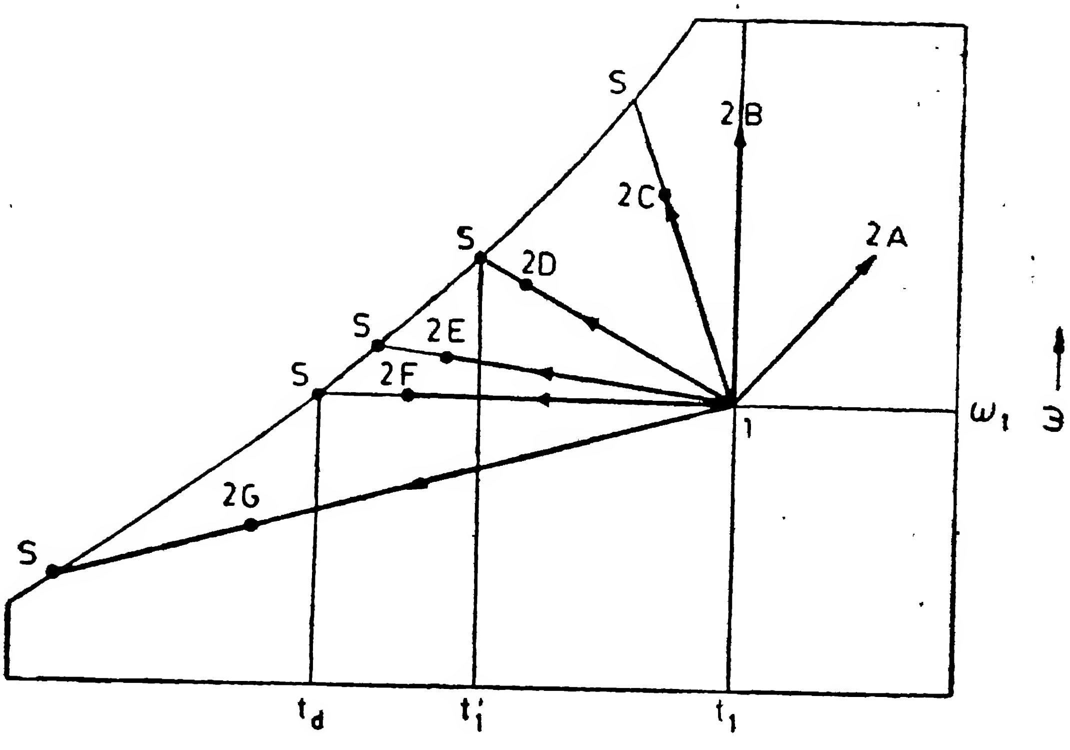
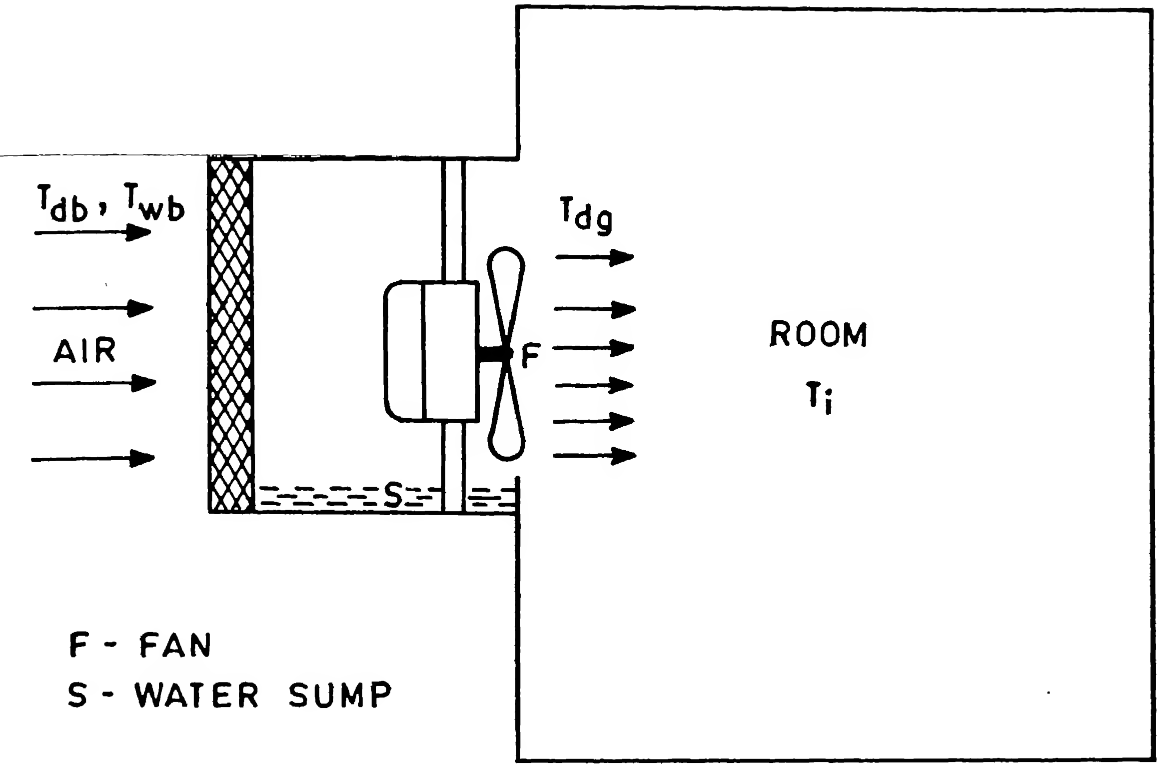
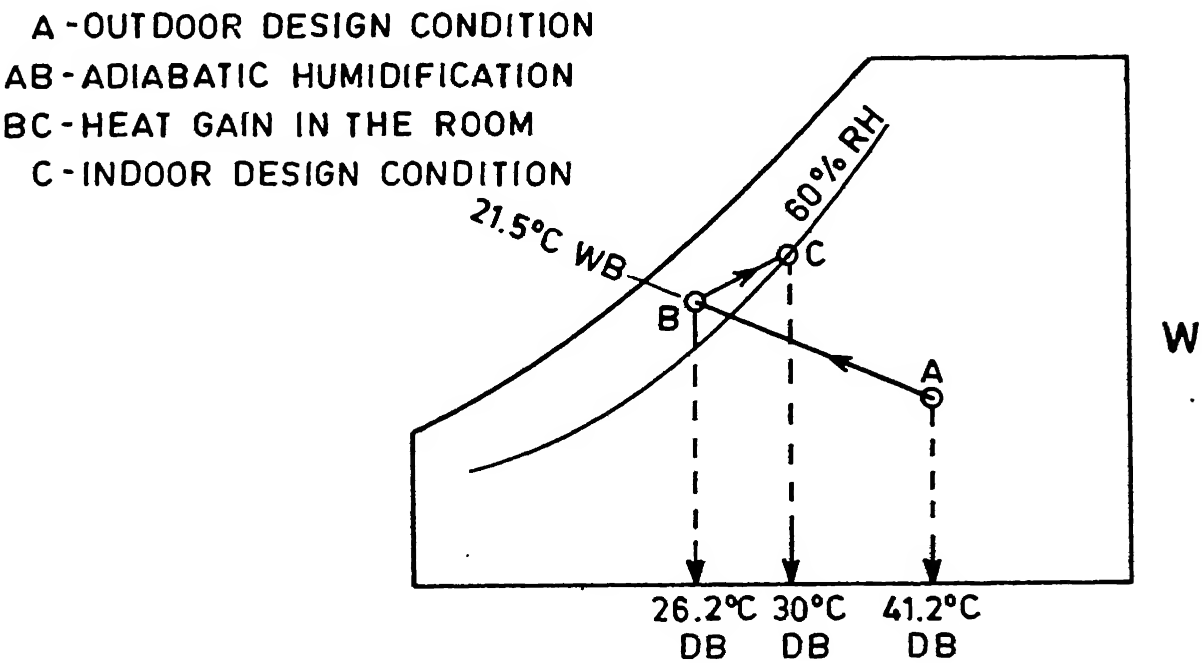


Fig. 3.4 Range of psychrometric processes with an air washer



(a)



(b)

Fig. 3.5 (a) Evaporative cooling arrangement in room.
(b) Evaporative cooling process.

3.5 COMFORT AIR CONDITIONING FOR INLAND AREAS

Since, all small conditioning units for comfort only undertake cooling, we shall limit our attention to the months from April to September. During the months of October, November, December, January, February and March the climatic conditions are either pleasant or cold and hence there is no scope for cooling.

As can be seen from the Figs. 3.6(a-f), one can reach the comfort zone with the help of desert cooler for most of the time in the months of April, May and June except during the morning hours. However, during the month of July we find that some points lie above the limit line for evaporative cooling and some below it. Hence, though, the desert cooler shall be effective for some period of day it shall be useless for the remaining part. In the months of August and September it is invariably found that the evaporative cooling process is ineffective. The comfort zone can only be approached by mechanical cooling process, viz., cooling and dehumidification due to high ambient humidity.

Thus, we find that though the evaporative cooling system is highly energy effective one can not do away with

the mechanical coolers. Surprisingly, it is also found that window air conditioners which are power guzzlers are incapable of providing the comfort condition during the dry periods of the year.

Hence, we find that there is a need of a system which shall work as an evaporative cooler but is capable to manipulate as mechanical cooler when the desert cooler becomes ineffective. The above system shall be capable of meeting the air conditioning requirement for the greater part of the year and shall also be great energy saver. Air conditioning performance lines for the conventional air conditioner and the new hybrid system are shown in Fig. 3.7.

With these considerations in mind, hybrid system has been developed, which has an evaporative condenser and has the capacity to work both as evaporative cooler and as mechanical cooler.

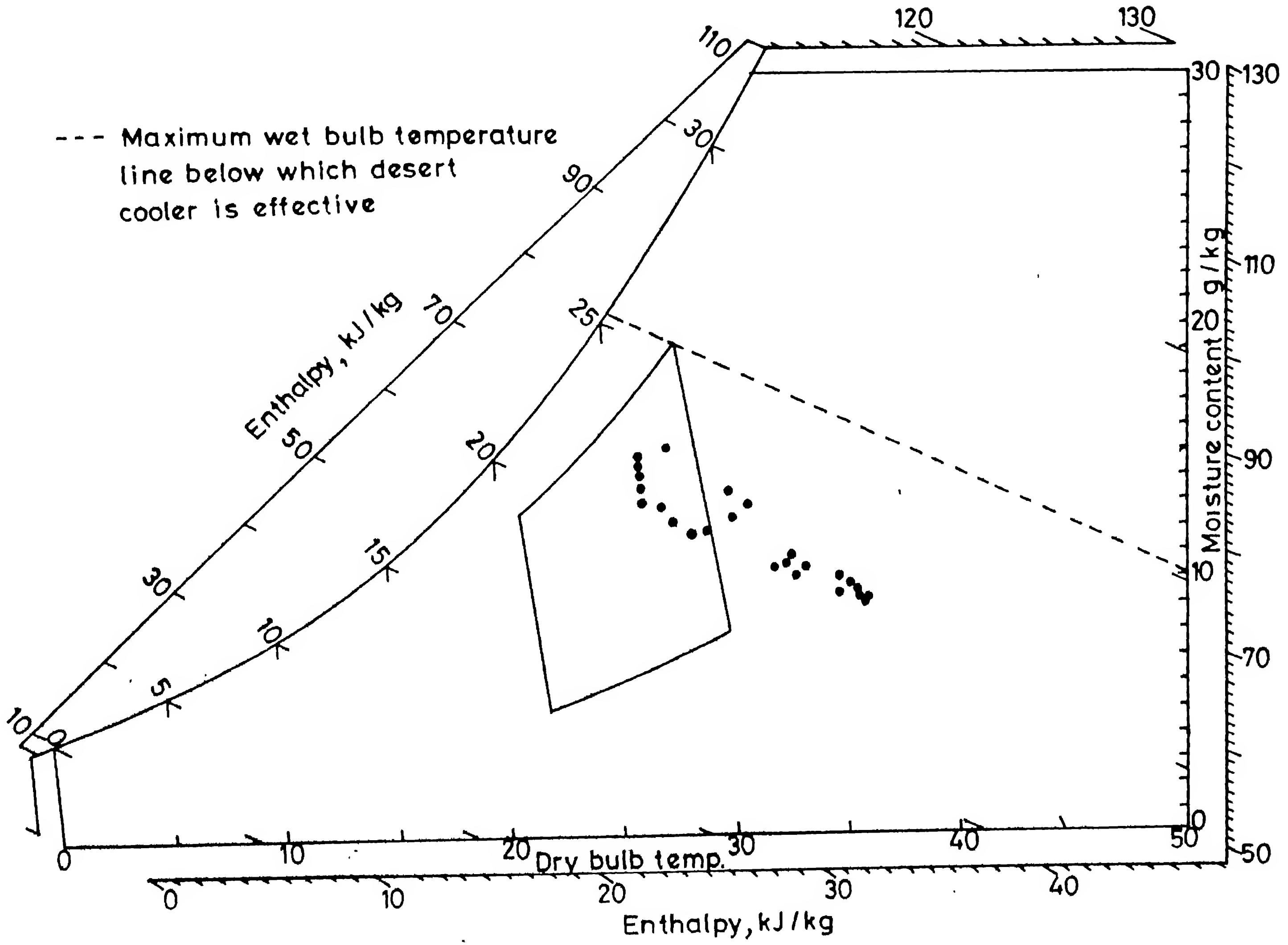


FIG.3.6(a) AMBIENT CONDITIONS OF KANPUR FOR THE MONTH OF APRIL

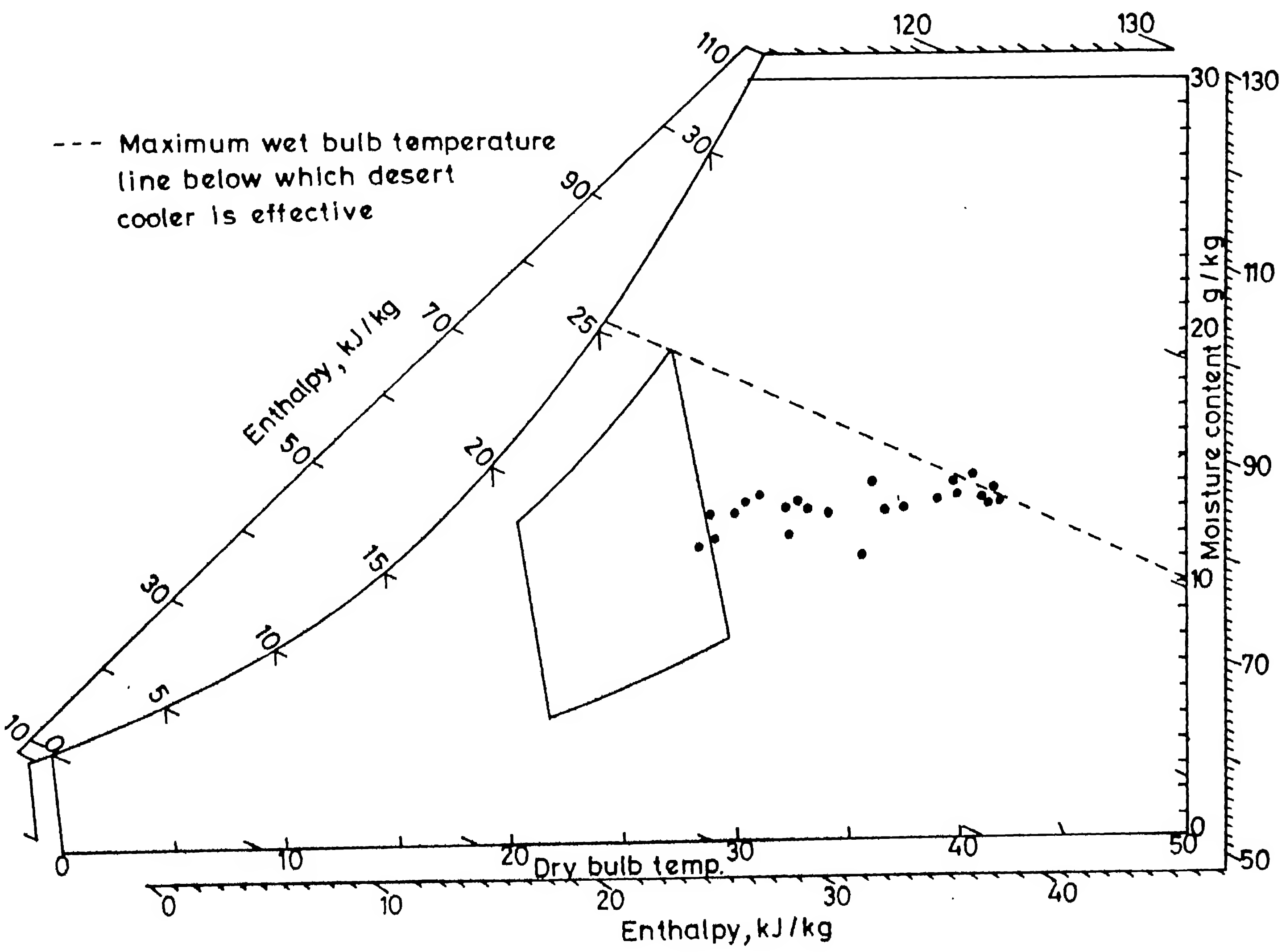


FIG.3.6(b) AMBIENT CONDITIONS OF KANPUR FOR THE MONTH OF MAY

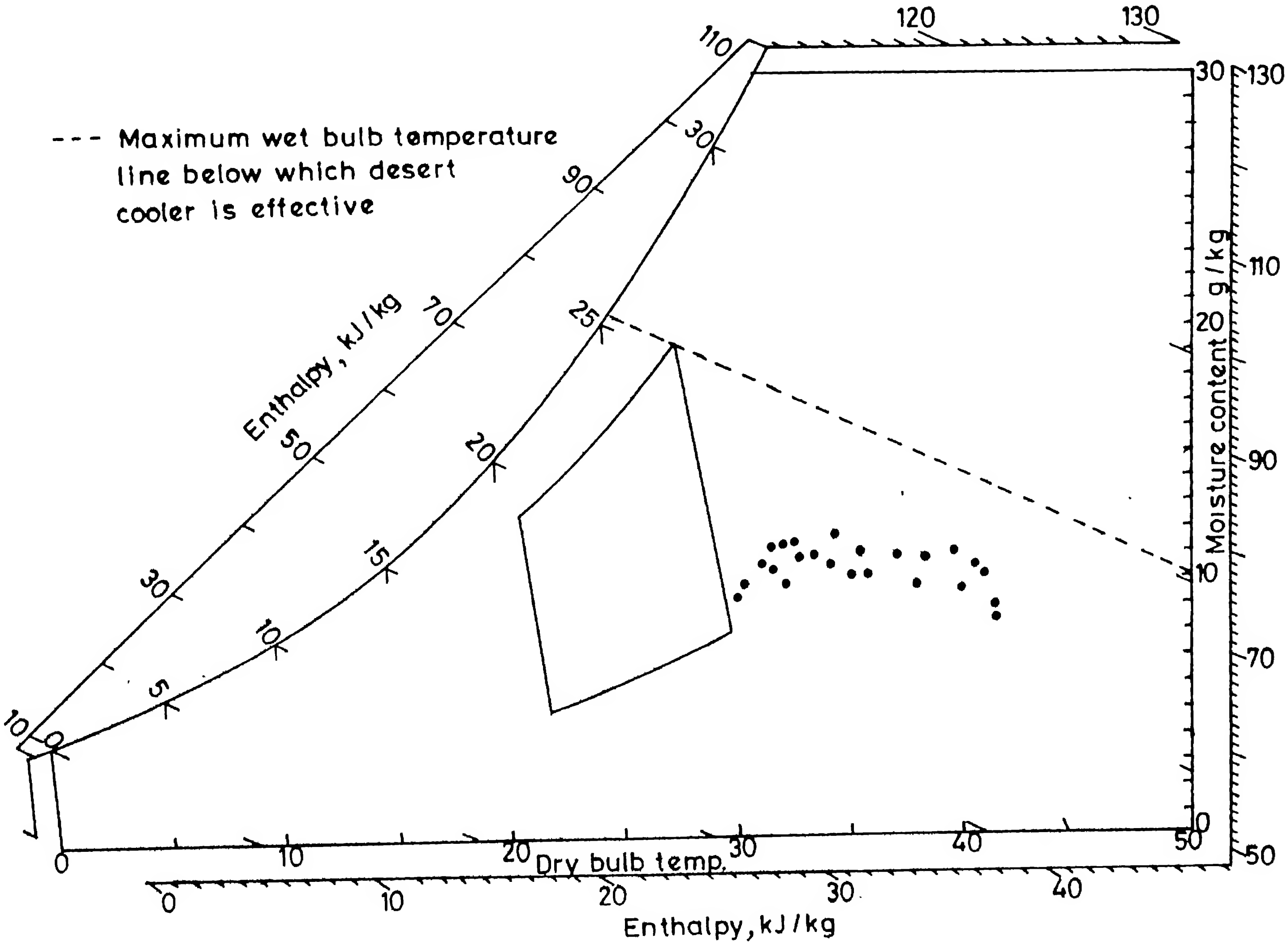


FIG.3.6(c) AMBIENT CONDITIONS OF KANPUR FOR THE MONTH OF JUNE

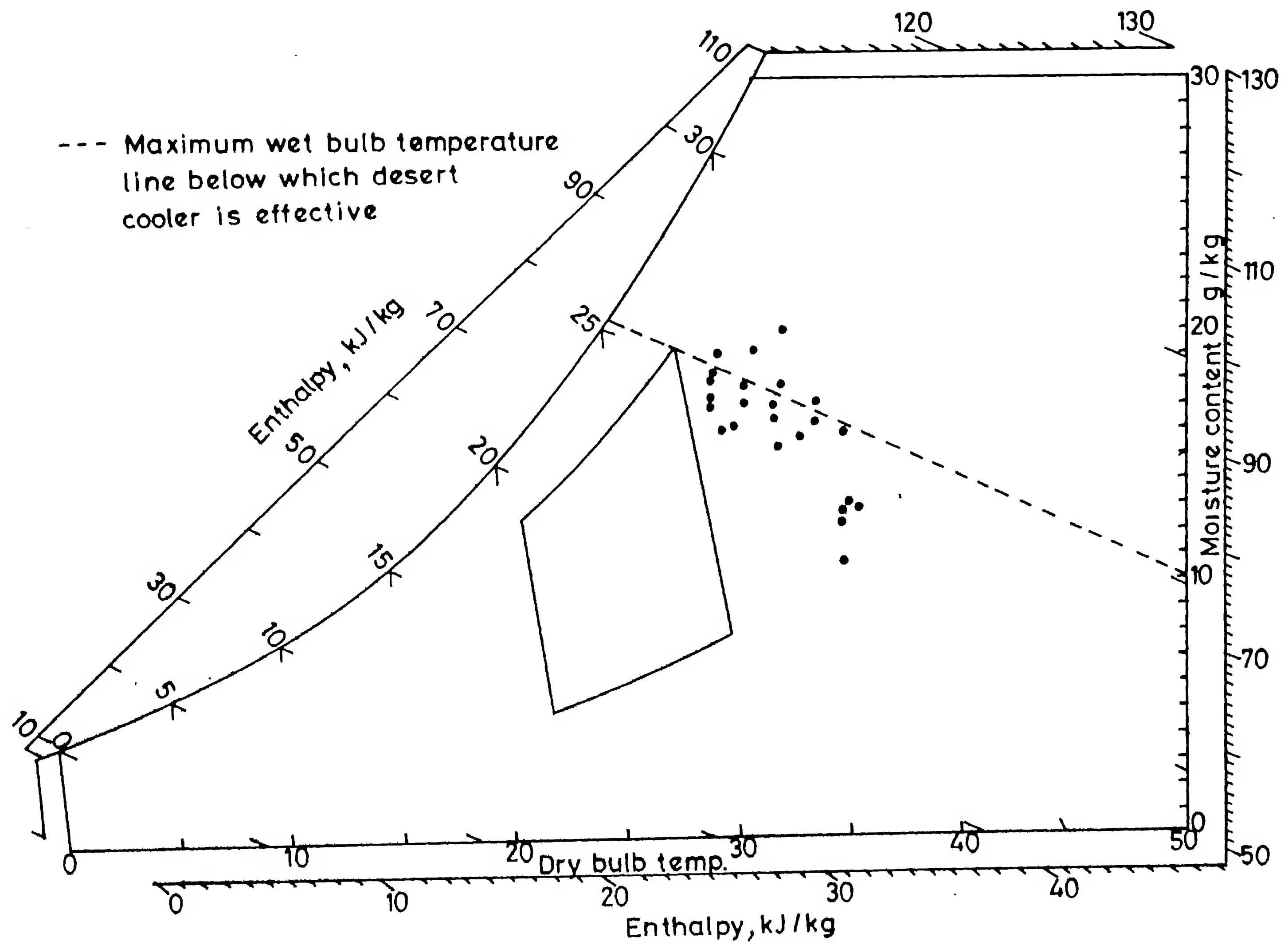


FIG.3.6(d) AMBIENT CONDITIONS OF KANPUR FOR THE MONTH OF JULY

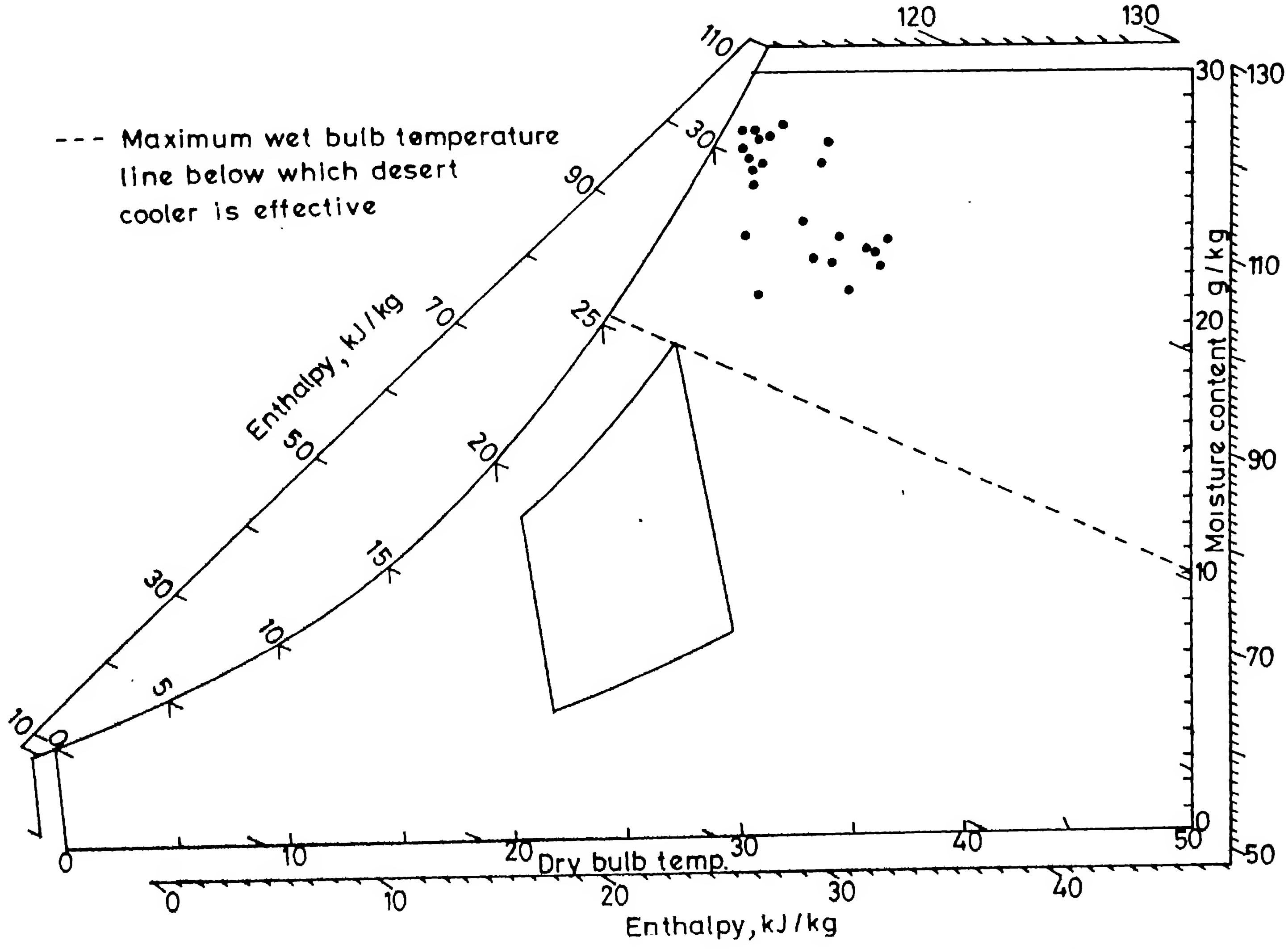


FIG.3.6(e) AMBIENT CONDITIONS OF KANPUR FOR THE MONTH OF AUGUST

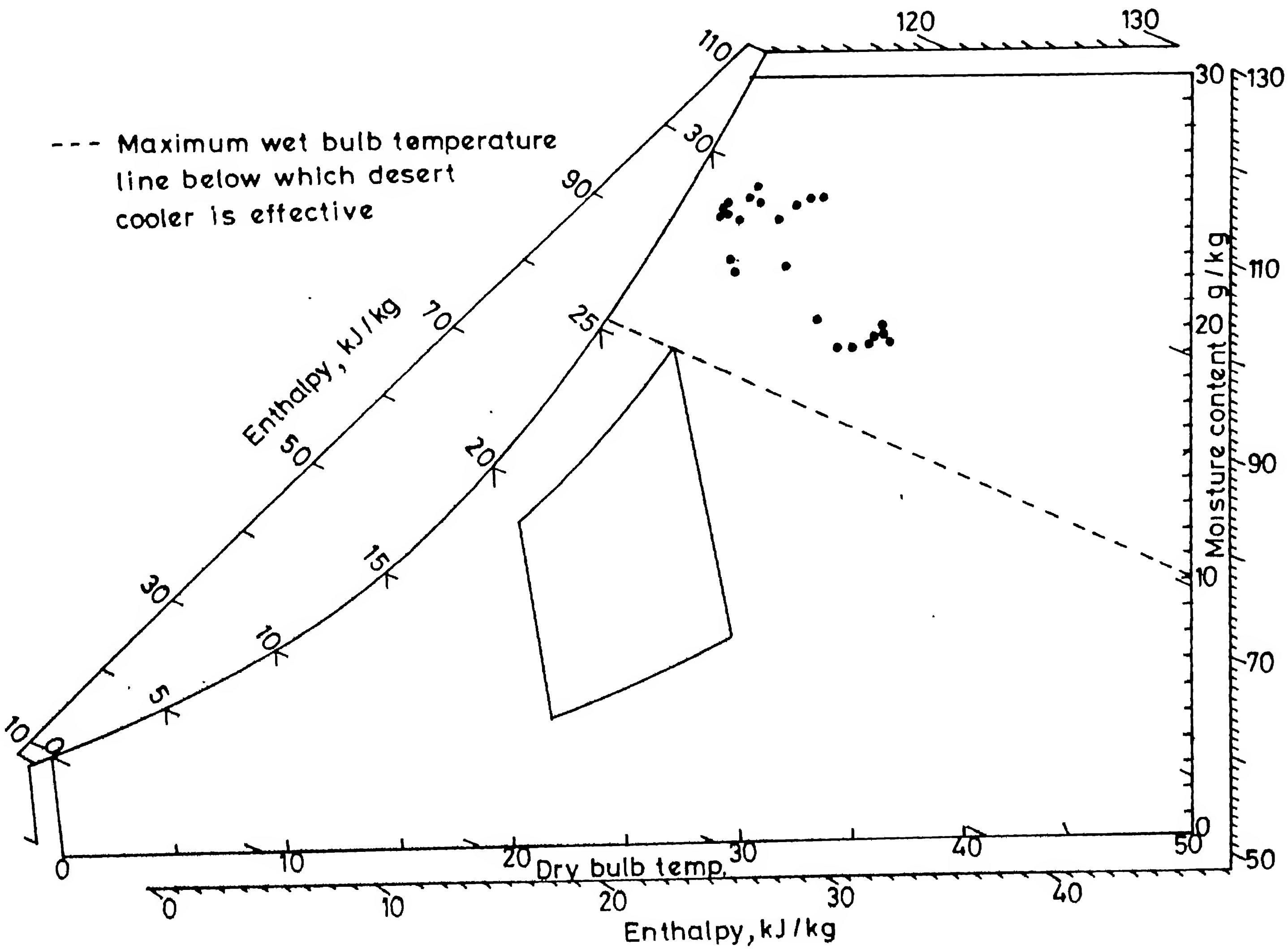


FIG.3.6(f) AMBIENT CONDITIONS OF KANPUR FOR THE MONTH OF SEPT.

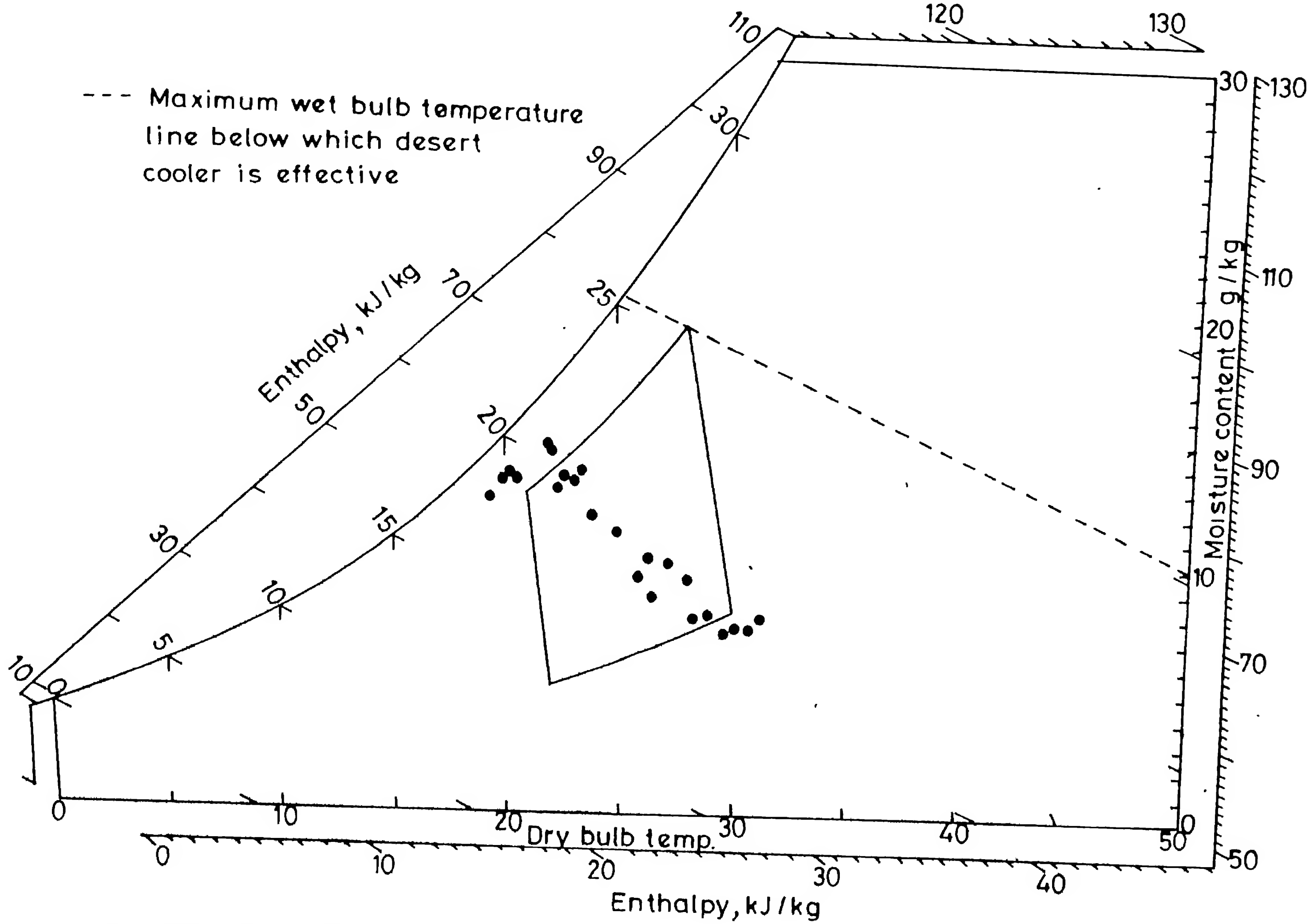
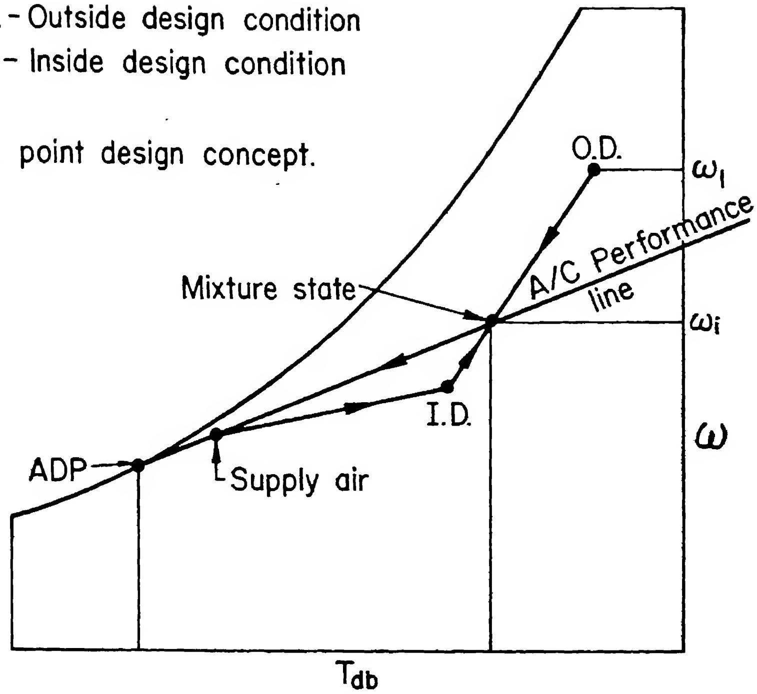


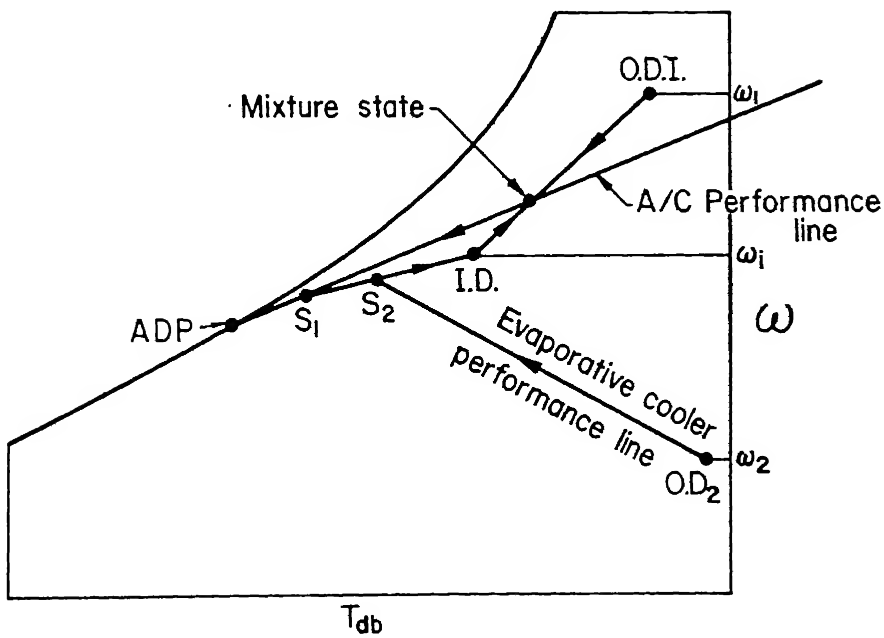
FIG. 3.6(g) AMBIENT CONDITIONS OF KANPUR FOR THE MONTH OF OCTOBER

O.D. - Outside design condition
I. D. - Inside design condition

One point design concept.



Conventional operation A/C



New hybrid air conditioning operations

Fig. 3.7 Performance lines for air conditioning

CHAPTER 4

DETAILS OF HYBRID SYSTEM

4.1 GENERAL DESCRIPTION

As has been brought out in the last chapter the hybrid air conditioning system has been developed incorporating the features of both window air conditioner and desert cooler.

The system has been designed for 1 ton cooling load. It consists of an evaporator, a capillary tube, an expansion valve, a compressor, an evaporative condenser, a water tank, a water pump and two blowers. Besides, these components wattmeters, rotameter and high pressure and low pressure gauges were incorporated in the system. These along with an aspirated psychrometer have been used for measuring the various parameters for evaluating the performance of the system.

Inorder, to compare the working of the hybrid system with the existing systems it was decided that minimal changes be introduced in the existing designs. Hence, the same components except the condenser have been used. The air-cooled condenser has been replaced by an evaporative condenser. This results in lower head pressure. To take it into account a parallel expansion valve was used so that

the required throttling may be achieved.

4.2 EVAPORATIVE CONDENSER

Like the water-cooled and air-cooled condensers the basic purpose of the evaporative condenser is to reject the heat from the condensing vapour into the environment. Infact, the evaporative condenser may be thought of as merging of a water-cooled condenser and an air-cooled condenser which utilizes the principle of heat rejection through the evaporation of water into a stream of air travelling across the condenser coil.

Evaporative condenser eliminates the need for the pumping and chemical treatment of large quantities of water associated with cooling tower/ refrigerant condenser systems. In addition they require substantially less fan horsepower than air-cooled condensers of comparable capacity.

The evaporative condenser allows for a lower condensing temperature than an air-cooled condenser because the heat rejection in an air-cooled condenser is limited by the ambient dry-bulb temperature. In the evaporative condenser heat transfer is limited by the wet bulb temperature which is normally 8 to 20 C, ie., much lower than the ambient dry-bulb temperature. The heat transfer in the water-cooled condenser takes place in two

stages : first from the refrigerant to the cooling water and then from water to the ambient air. Hence, the evaporative cooler also provides lower temperature than the water-cooled condenser as the heat transfer takes place directly to the water.

In an evaporative condenser vapour to be condensed is circulated through a condensing coil that is continuously wetted on the outside by the recirculating water. As seen in Fig. 4.1, air is simultaneously directed across the coil causing a small portion of the recirculated water to evaporate. This evaporation results in the removal of the heat from the coil thus cooling and condensing the vapour.

In an evaporative condenser, heat flows from the condensing refrigerant vapour inside the tubes, through the tube wall, to the water film outside the the tubes, and then to the air. Figure 4.2 shows temperature trends in an evaporative condenser [19]. The driving potential in the first step of heat flow process is the temperature difference between the condensing refrigerant and the surface of the water film, whereas, the driving potential in the second step is a combination of temperature and concentration difference between the water surface and the air.

As can also be noted from Fig. 4.1 if no refrigerant

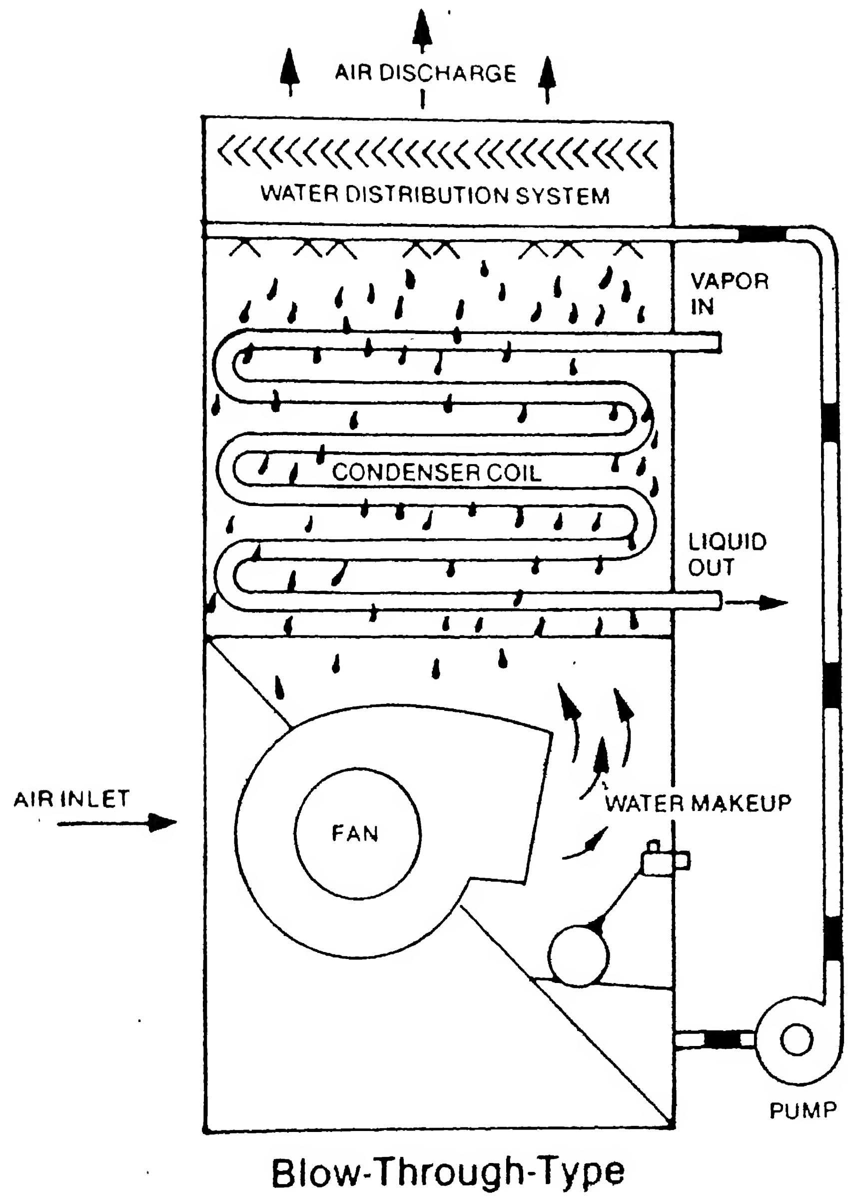


Fig. 4.1 Functional View of Evaporative Condenser

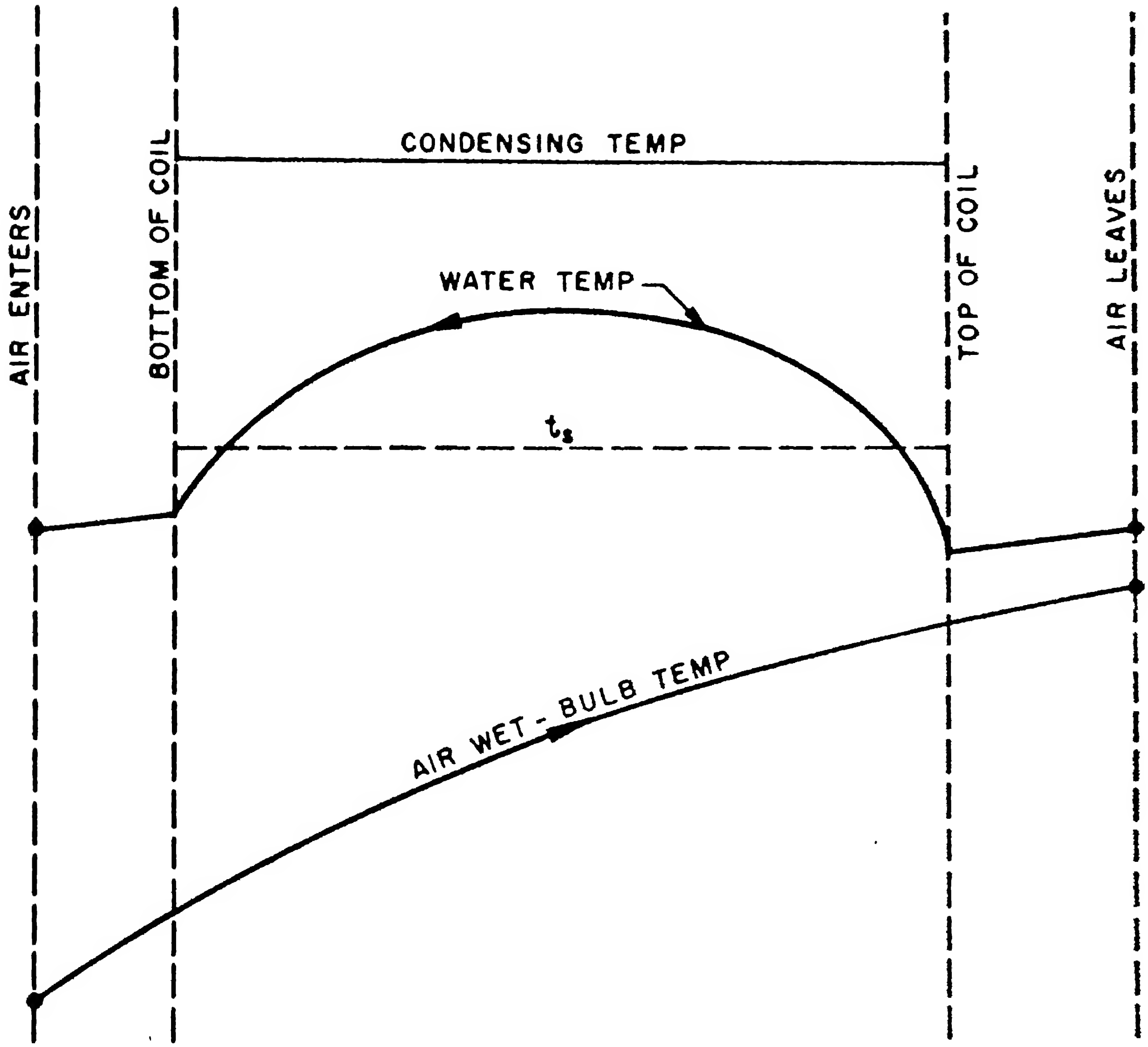


Fig. 4.2 Heat-Transfer Diagram for an Evaporative Condenser

is flowing through the coils, there is no heat rejection and the condenser acts as an air-washer with the recirculated water at the wet-bulb temperature. The air which passes through such an air-washer gets cooled and humidified adiabatically along the constant wet-bulb temperature line. This is exactly the same process that takes place in the desert cooler.

Hence, we find that the evaporative condenser can also perform as a desert cooler and is an ideal choice for the hybrid system. Keeping into the consideration an evaporative condenser has been incorporated in the designed hybrid system.

4.3 MATHEMATICAL ANALYSIS

Referring to Fig. 4.3, the cooling load for the building/room is calculated from the knowledge of inside and outside design conditions for hot-dry and hot-humid climate. Thus, the structural heat load including solar radiation is found to be [18].

$$\dot{Q}_1 = AU\,[(\bar{T}_{sa} - T_i) + \lambda(T_{sa-\tau} - \bar{T}_{sa})] \tag{4.1a}$$

When complete temperature time history for the whole day is not known or otherwise :

$$\dot{Q}_1 = AU\,(T_a - T_i)\,F \tag{4.1b}$$

where, F is the factor which accounts for the solar radiation as well.

The infiltration as ventilation load is taken to be

$$\dot{Q}_2 = V(h_a - h_i)/V_a \tag{4.2}$$

where,

$V = V_{in} + V_{vent}$

h_a and h_i are the enthalpies of ambient and inside air on the respective design conditions and V_a is the specific volume of the air.

The heat load due to light and electric appliances are found from

$$\dot{Q}_3 = \sum_j N_j P_j \text{ light} + \sum_l (N_l \; P_l . OF)_{M/C} \tag{4.3}$$

The heat load due to occupants is found from the number of persons and their activity level, i.e.

$$\dot{Q}_4 = \sum_k N_k \; P_k \tag{4.4}$$

The total heat load is

$$\dot{Q}_{total} = \sum_{i=1}^{4} Q_i \tag{4.5}$$

The design heat load is found from

$$\dot{Q}_{design} = SF . \dot{Q}_{total} \tag{4.6}$$

where, SF is the safety factor, usually taken as 1.1

Then the capacity of the conventional air conditioning system is

$$TR = \dot{Q}_{design}/3.5 \tag{4.7}$$

Select from the available commercial sizes.

For the evaporative cooling operation, ignore the infiltration and ventilation load, then

$$\dot{Q}_{total} = \dot{Q}_1 + \dot{Q}_3 + \dot{Q}_4 \tag{4.8}$$

and,

$$\dot{Q}_{design} = SF.\dot{Q}_{total} \tag{4.9}$$

Let T_{db}, T_{wb} be the outside design conditions and η the efficiency of the evaporative cooling device. Then the temperature of the air leaving the grille :

$$T_{dbg} = T' - \eta\,(T_{db} - T_{wb}) \tag{4.10}$$

T' is the dew point temperature of ambient air.

If the temperature rise of the air across the room is ΔT for once through air cooling, the volume air circulation is found to be :

$$V_{cir} = \dot{Q}_{design}\, V_a / \,(1.026 \times \Delta T) \tag{4.11}$$

Where 1.026 kJ/kg is the average specific heat of the moist air. Sometimes, the air circulation in evaporative cooling is calculated on the basis of the number of air changes. Generally there are 15 to 30 n_{ch} (Number of air changes per hour). One gets the volume of evaporatively cooled air as

$$V_{cir} = n_{ch} \times V_{room}$$

where, V_{room} is the volume of the room.

4.4 DETAILS OF THE SETUP

Figure 4.4 exhibit the designed set-up schematically (see photograph also). The blower (230 V, 100 W) is used to suck air through the condenser whose pipes are embedded

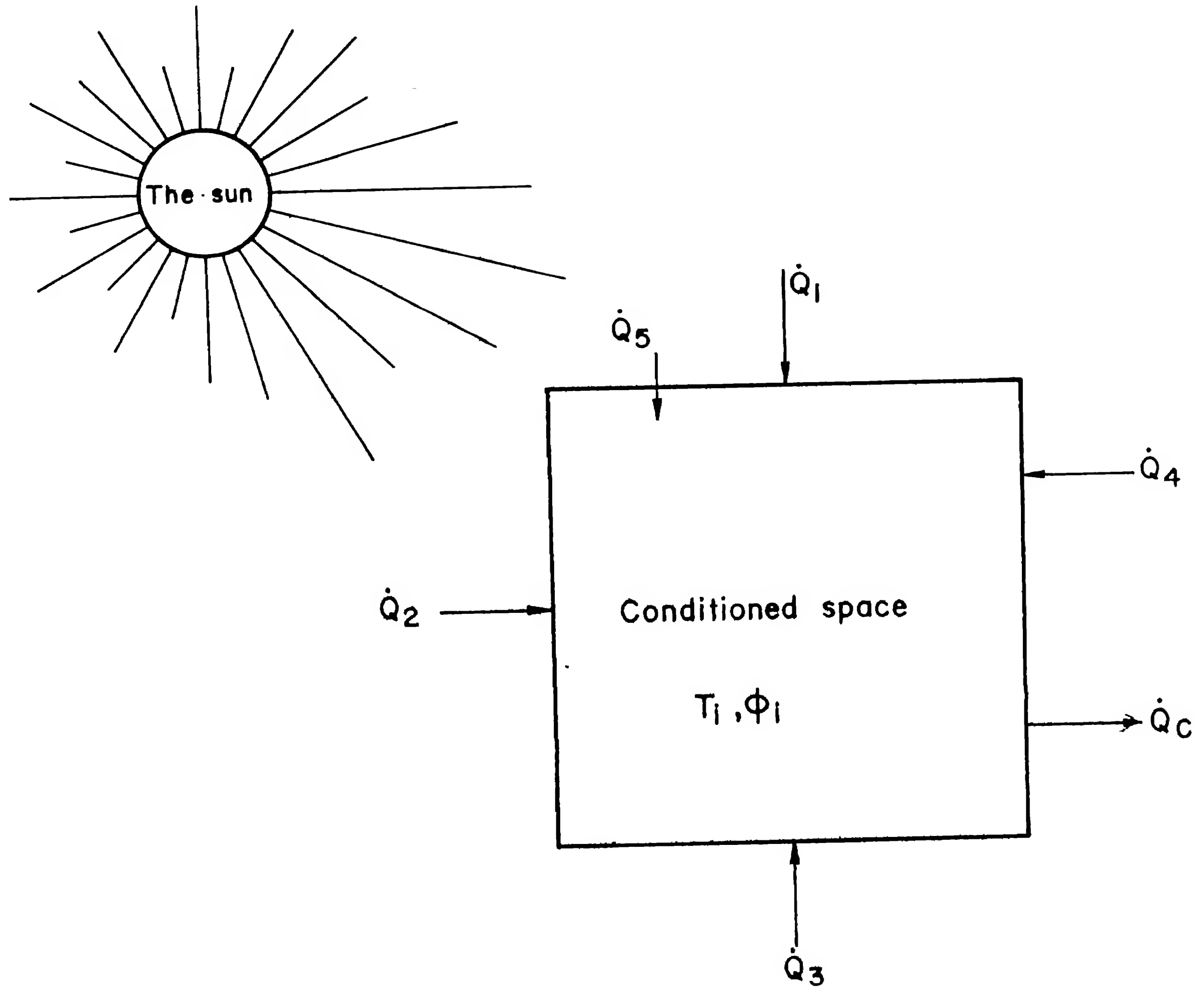


Fig. 4.3 Energy balance for conditioned space

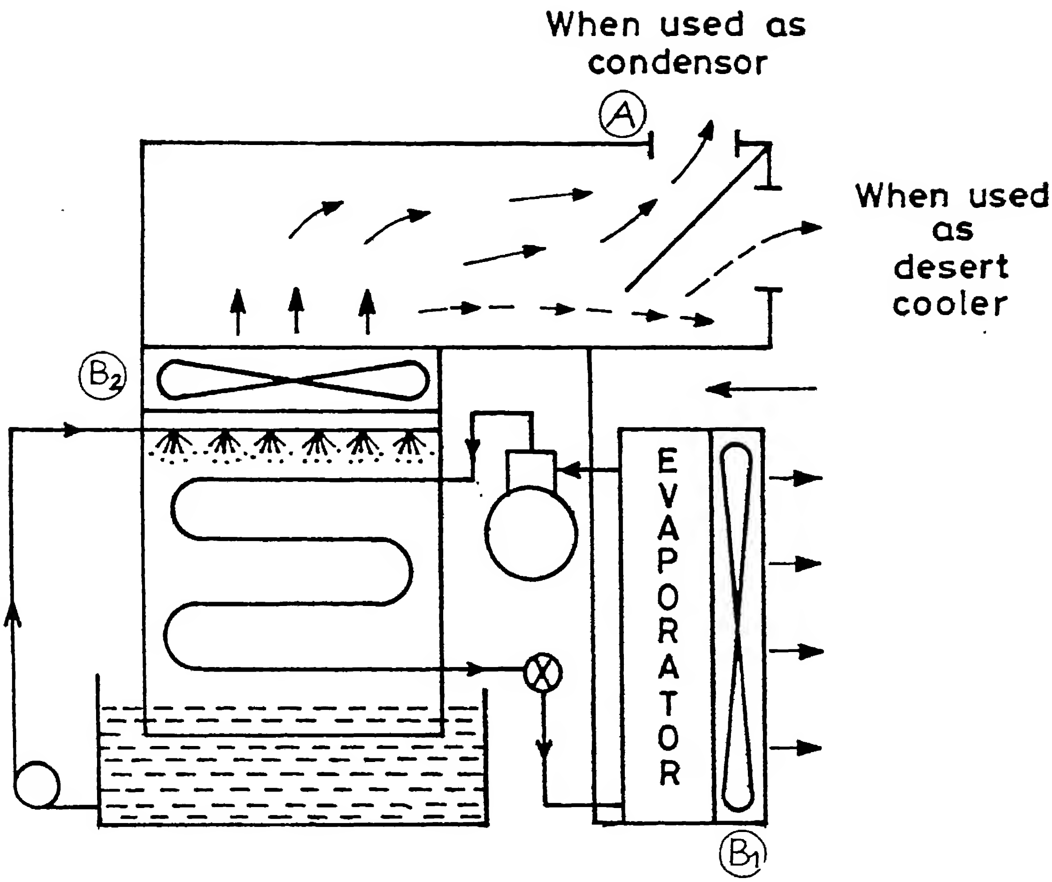


Fig. 4.4 Schematic diagram of the hybrid system

in the wood wool pad. The water is continuously pumped and recirculated by a horizontal centrifugal pump (230V, 25W). The wood wool pads are wetted by the water dripping through the perforated pipe mounted at the top of the condenser.

The sucked air is passed through the duct which leads to the open environment when the system operates as an air conditioner. However, if the system works as desert cooler the flap is moved to a position A of the duct and the air is supplied to the room. Thus the room gets cooled by the humidified air.

The power consumed by the blower and the compressor is measured by the wattmeters with range (0-250 W and 0-2500 W). The flow rate of the water is measured with the help of a calibrated rotameter. The suction and discharge pressures are obtained with the help of the calibrated pressure gauges of the range (150 psi and 300 psi). The discharge of air from the evaporator and the condenser/ evaporative cooler is determined with the help of anemometer and stop-watch.

When the system is used in the evaporative cooling mode, it works as an once through cool air supply device such that the cool air from the system cools the room and gets discharged to the atmosphere. In case of air

conditioning mode, the room air is recirculated again and again after cooling and dehumidification. The ventilation air is also supplied through the cooling coils in this case.

The electrical switches of the system and the flap are provided in such a way that the system can be operated as per the desire of the users. Even during the rainy season, when in the forenoon the temperature is low, the evaporative cooling may be preferred though it amounts to a little sacrifice in the comfort level in order to conserve the energy.

When the system operates as an air conditioner both blowers B_1 and B_2 are in operation. On the other hand when it is desired to work the system as an evaporator cooler, the compressor and the blower B_1 are switched off.

4.5 CALIBRATION OF ROTAMETER

In order to attain accuracy in the volume flow rate of the water across the tubes of the condenser over the wood wool pad the rotameter was calibrated with the help of measuring cylinder and stop-watch. The actual and measured values have been plotted in Fig. 4.5.

4.6 CALIBRATION OF PRESSURE GAUGES

The pressure gauges used in the system are calibrated as per the ISI specifications in the laboratory using

standard dead weight pressure gauge. The actual and the measured values have been plotted in Figs. 4.6 & 4.7 to obtain the accurate value of pressure.

4.7 EXPERIMENTAL DETAILS

First of all the dry-bulb and the wet-bulb temperature of the ambient air is observed with help of an aspirated psychrometer. The state point is plotted on the psychrometric chart. The possibility of achieving comfort condition using evaporative cooling is explored. If possible the evaporative mode of cooling is used otherwise mechanical cooling is used.

When the system works as an evaporative cooler, only ambient conditions and discharge condition to the room are obtained with the help of an aspirated psychrometer. The energy consumed by the blower and the flow rate of the water are recorded using wattmeter and rotameter respectively.

In case of the system manipulating as an air conditioner, the ambient condition, discharge condition to the surroundings, the suction and discharge conditions are noted down from the psychrometer. Also the power for the blower and the compressor are measured by the wattmeters. Besides these observations the suction and discharge pressures are read from the pressure gauges.

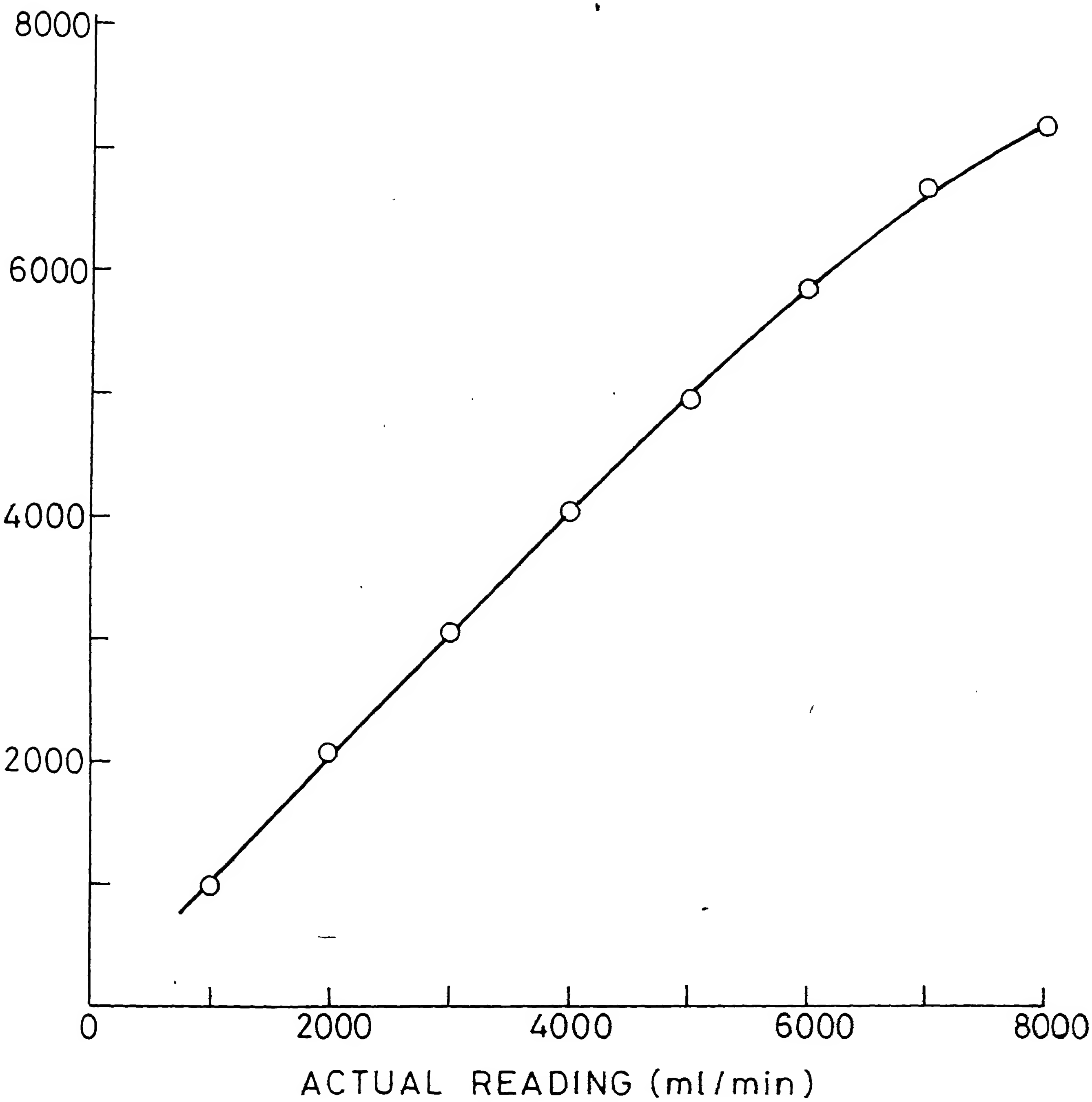


FIG. 4.5 CALIBRATION OF ROTAMETER

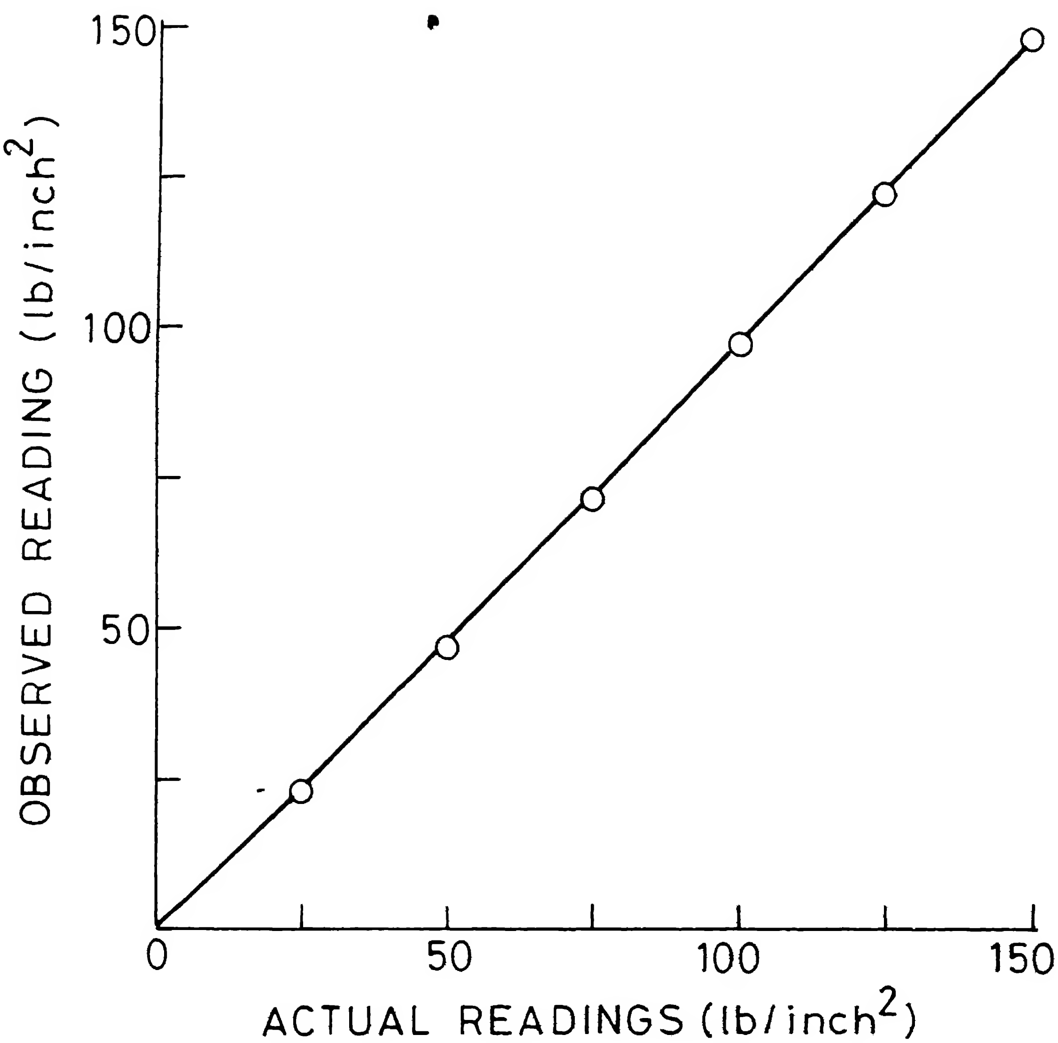


FIG. 4.6 CALIBRATION OF LOW PRESSURE GAUGE

CHAPTER 5

RESULTS AND DISCUSSION

5.1 INTRODUCTION

A comparative economic analysis has been done for the three systems :

(A) A conventional air conditioner

(B) Combination of a conventional air conditioner and a desert cooler and

(C) A hybrid system

The present worth economic model has been used to evaluate the total cost comprising the initial investment and the running cost.

Then, the physical specifications of the system were worked out. Also, the actual cooling effect, heat rejected and power consumed have been measured and recorded.

5.2 ECONOMIC ANALYSIS

The one ton window air conditioner costs Rs.15,000/-, the desert cooler costs Rs.2,500/- whereas the hybrid system costs Rs. 15,800/- [Appendix D]. The power consumed by the window air conditioner is 1.7 kW [20], the desert cooler consumes 250 W and the hybrid system 1580 W.

Assuming the life of air conditioner and hybrid system to be 20 years and that of the desert cooler to be

10 years and the maintenance cost to be 10% of the initial cost [21], the total cost is estimated using present-worth method [Appendix E].

The computed values for the operating hours of 6,8,10,12 and 14, the rate of interest as 10% and cost multiplication factor for the desert cooler, $\beta = 2$, are shown in Table 5.1 and 5.2.

Table 5.1

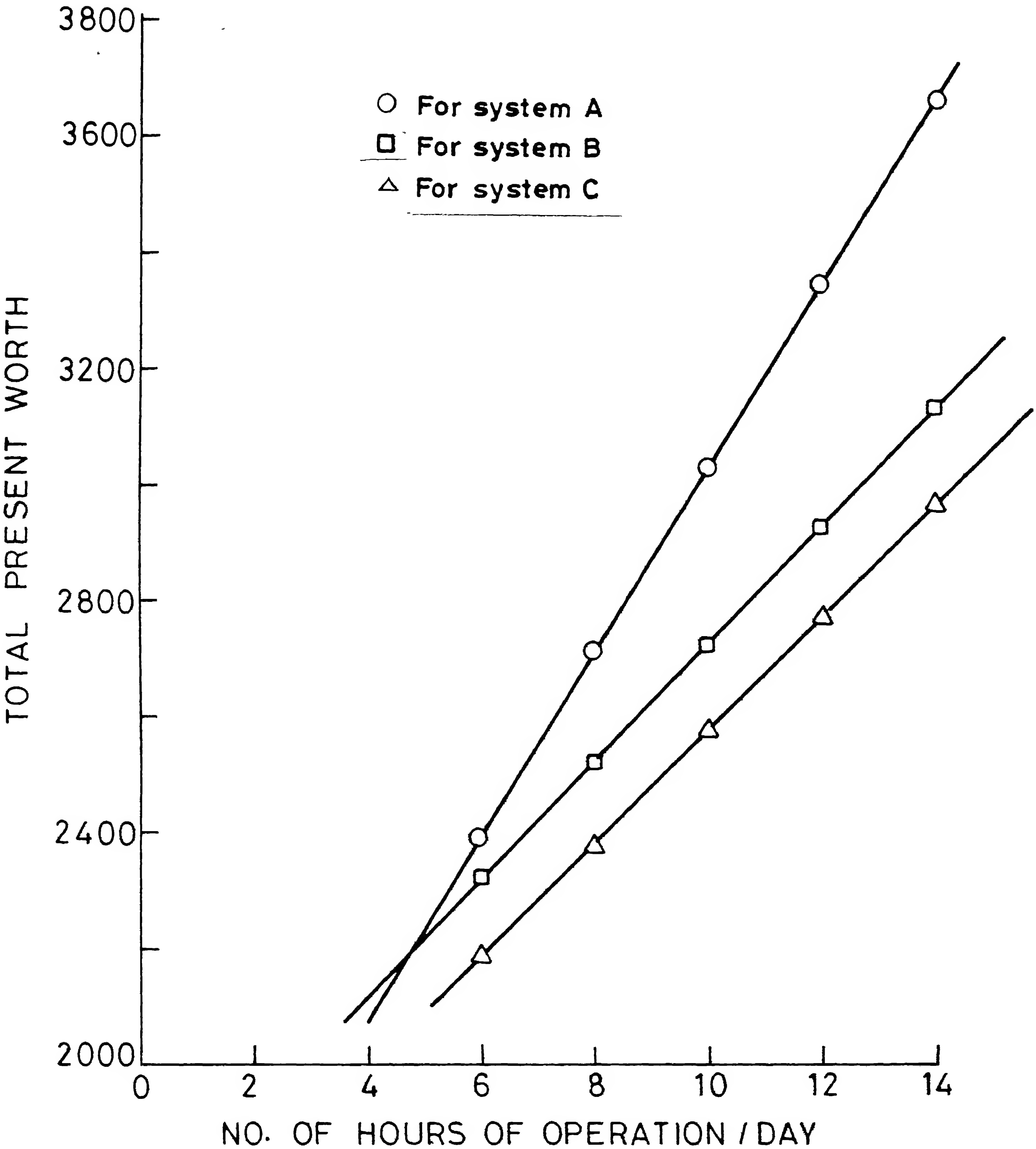
Total cost of various systems

No. of hours of operation	Total Cost System A	System B	System C
6	2398.31	2322.74	2186.67
8	2717.63	2525.60	2385.10
10	3036.96	2728.47	2583.51
12	3356.28	2931.33	2781.93
14	3675.59	3134.20	2980.31

Table 5.2

Saving in cost using the Hybrid system, C

No. of hours of operation	% average reduction in cost using System C over System A	over System B
6	9.67	6.22
8	13.94	5.89
10	17.55	5.61
12	20.64	5.37
14	23.33	5.16



For system A
For system B
For system C
TOTAL PRESENT WORTH
3800
3600
3200
2800
2400
2000
0
2
4
6
8
10
12
14
NO. OF HOURS OF OPERATION / DAY

FIG. 5·1

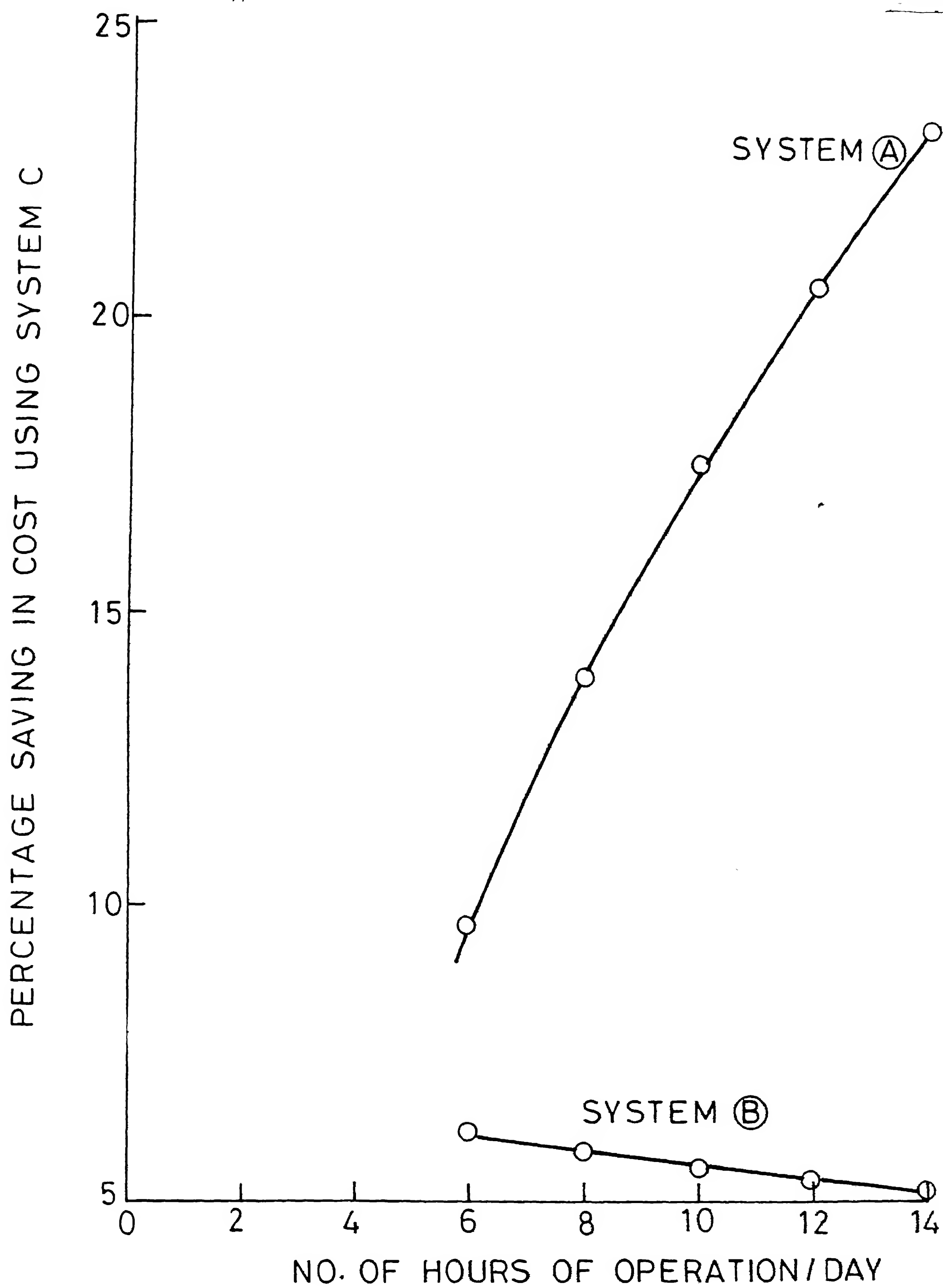

PERCENTAGE SAVING IN COST USING SYSTEM C
25
20
15
10
5
SYSTEM Ⓐ
SYSTEM Ⓑ
0
2
4
6
8
10
12
14
NO. OF HOURS OF OPERATION / DAY

FIG. 5·2

Figure 5.1 exhibits that the total present worth of the hybrid system is lower than those of the other systems. The hybrid system is found to be cheaper than the systems A and B for almost all practical values of working hours due to lower power consumption. Interestingly, even the combination system B is found to be economical to the conventional system A for 5 hours or more operating period per day.

The saving in cost for system C compared to system A and B is shown in Fig. 5.2.

5.3 SYSTEM SPECIFICATIONS

After establishing the economic feasibility of the hybrid system its physical specifications were worked out. The specifications for the room for which the cooling load has been estimated is given in appendix F. Inorder to show the decrease in cooling load when the inside conditions are modified from the conventional conditions of IDT= 25 C and Ø =50% to IDT = 30 C and Ø = 60%, the cooling load has been calculated for both during the summer and the rainy season. The outside design conditions are taken as T_{db}=41.2 and T_{wb}=21.5 C and T_{db}=32.1 and T_{wb}=28.8 for summer and rainy season respectively. The results are given in table 5.3.

Table 5.3

Cooling load for summer and rainy season

S. No.	IDT	Cooling load for summer season	Cooling load for rainy season
1.	25	4.260	5.586
2.	30	2.836	4.235

It should be noticed that for summer season when the inside design temperature is 30 C the enthalpy of outside air is less than that of the inside air and hence the ventilation and infiltration load is negative. For the room in question it is -635 W. However, since there is no provision of evaporative cooling in the air conditioner this can not be utilised to reduce the energy consumption. This once again highlights the necessity of the hybrid system.

It should also be noted that as the IDT is increased from 25 C to 30 C it may be assumed, though not very rigorously, that the evaporator temperature increases from the conventional value of 7 C [22] to 12 C. Energy requirement of the system with same condensing temperature, viz., 45 C and evaporator temperature of 7 C and 12 C has been calculated for a simple vapour compression cycle, with superheat of 15 C, to show the power saving in summer and rainy season in table 5.4.

Table 5.4

Comparative power consumption for IDT=25 C and 30 C			
S.No.	IDT	Power consumption in kW	
		Summer season	Rainy season
1.	25	0.826	0.944
2.	30	0.283	0.543

For the same room,the air requirement was evaluated, for the evaporative cooling, taking the effectiveness of evaporative cooler to be 75%. It is found that 28 air changes/hour are required to meet the comfort requirement during summer.

5.4 PERFORMANCE AS EVAPORATIVE COOLER

Next, an actual hybrid system has been developed. The system has been found to be capable of meeting comfort conditions using evaporative cooling during the months of April, May and June. The effectiveness of the system has been calculated. The results for every Monday are shown in Table 5.5. It is also found that the evaporative method of cooling is ineffective during the months of July, August and September due to high level of humidity.

Table 5.5

Ambient condition at noon and the effectiveness of the Desert Cooler on Mondays

Face area of wetted pads = 1.2 sq.m.

Water flow rate through pads = 0.085 kg/s.

Air flow rate across pads = 0.2322 kg/s.

Pressure drop across pads = 12.3 mm of water.

Date	Ambient Condition		Discharge Condition		Effectiveness
	DBT (C)	WBT (C)	DBT (C)	WBT (C)	%
4.4.88	33.3	20.3	22.1	20.4	86.15
11.4.88	34.2	21.2	26.8	22.5	61.54
18.4.88	34.7	23.6	26.6	23.8	72.97
25.4.88	35.1	24.2	26.2	24.4	74.79
2.5.88	35.0	23.4	25.8	23.6	79.31
9.5.88	36.2	22.7	25.6	22.8	78.52
16.5.88	36.7	22.9	26.3	23.0	75.36
23.5.88	36.4	23.1	26.3	23.2	75.93
30.5.88	37.1	23.0	26.4	23.1	75.88
6.6.88	38.4	22.2	25.8	22.4	89.36
13.6.88	37.8	22.1	25.6	22.3	80.25
20.6.88	34.1	24.3	26.1	24.5	81.36
27.6.88	32.6	30.1	30.2	30.2	96.00

5.5 PERFORMANCE AS AIR CONDITIONER

The results for the system operating as an air conditioner are given in table 5.4. The power consumption obtained by evaluating the difference of the heat rejection and heat absorption is found to be slightly less than the actual power consumed in the compressor. This discrepancy can be accounted for if we consider the heat rejected by the compressor to the surroundings and the small amount of heat carried away by the cooling water.

It is found that the power consumption in the compressor is lower than the power consumption as per the specifications of the manufacturer. This has been effected by bringing down the condensing temperature by using evaporative condenser and increasing the evaporator temperature, as higher IDT for comfort has been proposed. As such, it is noticed that the reduction in the power consumption is much more than the additional energy consumed by the pump to recirculate water.

Thus, we obtain greater COP when the system works in the air conditioning mode. This is an additional advantage of the hybrid system besides its performing as a desert cooler in dry periods.

Table 5.6 (a)

CONDENSER

Sl. No.	Ambient			Outgoing			Heat rejection
	T_{db}	T_{wb}	h_1	T_{db}	T_{wb}	h_2	
1	29.4	28.3	92.1724	35.3	32.1	112.3211	4.4118
2	30.6	29.5	97.2415	36.1	32.5	115.8342	4.317
3	30.0	29.4	97.0317	36.1	32.6	116.9841	4.6329
4	30.6	30.0	100.0017	35.8	34.0	119.6618	4.5651
5	32.1	30.3	103.7897	36.1	34.2	123.1682	4.9997
6	31.7	30.3	103.7574	35.8	34.1	122.9413	4.4545
7	31.3	30.0	100.0172	35.3	33.8	119.5171	4.5359
8	30.6	29.4	97.0718	36.1	32.4	116.1171	4.4223
9	30.0	29.5	97.1016	35.8	32.3	116.0785	4.4064
10	32.1	29.4	97.0919	36.5	32.6	117.1017	4.6463
11	31.8	30.1	101.8173	36.3	34.1	121.4144	4.5504
12	30.6	30.3	103.7273	36.1	34.3	124.0538	4.7206

Table 5.6 (b)

EVAPORATOR

Sl. No.	Incoming			Outgoing			Heat absorption	TR
	T_{db}	T_{wb}	h_1	T_{db}	T_{wb}	h_2		
1	27.8	26.7	84.0312	25.1	24.5	74.4736	3.2656	0.9330
2	28.3	27.8	87.2253	25.7	25.4	77.8733	3.1749	0.9071
3	27.8	25.9	80.4311	24.8	23.2	69.7713	3.6422	1.0406
4	27.2	25.9	80.3173	24.5	23.0	69.6818	3.6339	1.0383
5	27.2	25.6	79.1947	24.8	23.0	68.9345	3.5056	1.0007
6	26.7	25.6	79.1533	23.9	22.9	68.7232	3.5645	1.0184
7	26.7	25.9	80.3173	25.6	23.0	70.2137	3.4522	0.9863
8	26.1	25.0	76.7821	23.9	22.4	66.8117	3.4067	0.9733
9	26.1	24.5	75.6338	23.9	22.2	66.0862	3.2622	0.9321
10	27.2	25.4	80.3173	25.6	23.0	69.6818	3.5676	1.0193
11	26.1	25.0	76.7821	23.9	22.4	66.8817	3.4067	0.9733
12	27.2	25.6	79.1947	24.7	22.9	68.2171	3.7507	1.0716

Table 5.6 (c)

Power consumed when working as an air conditioner & its COP

Sl. No.	Power consumed		COP
	Actual	By heat balance	
1	1.400	1.1462	2.3326
2	1.400	1.1423	2.2678
3	1.350	0.9907	2.6979
4	1.300	0.9312	2.7999
5	1.350	0.9941	2.5961
6	1.300	0.8900	2.7419
7	1.350	1.0837	2.5572
8	1.350	1.0156	2.5235
9	1.400	1.1442	2.3301
10	1.350	1.0787	2.6422
11	1.400	1.1437	2.4333
12	1.350	0.9699	2.7783

5.6 CONCLUSION

As discussed in chapter 3 we see that to meet the comfort conditions both desert cooler and air conditioner are required in the large part of the country during different seasons of the year. Hence, the hybrid system which has been developed and tested is an ideal choice for the nation, in particular for the inland areas. We also find that, as expected, the hybrid system is a great energy saver. In view of the fast depleting conventional energy sources and the acute scarcity of electricity in India, the hybrid system is strongly recommended. It is suggested that further work be undertaken to improve the social acceptability by reducing its size, improving its appearance and making it more handy.

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TABLE A.2

Hourly outdoor relative humidity (%) for Kanpur from April to October taken as the average for three years, viz., 1982, 1983 and 1985

TIME	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
1	53.3	44.7	35.3	56.3	88.7	82.3	78.0
2	55.3	44.7	35.7	60.7	89.3	86.3	83.3
3	58.3	45.0	35.7	62.0	91.7	85.7	84.3
4	60.7	46.7	35.0	64.0	92.0	85.7	84.0
5	63.3	48.0	34.7	65.3	90.3	84.0	87.7
6	66.0	48.0	36.7	62.0	88.7	80.0	88.0
7	68.0	45.7	34.0	63.3	74.7	76.3	84.7
8	62.3	39.3	31.7	68.0	81.0	70.0	71.3
9	54.0	37.3	33.0	56.7	78.7	60.0	56.7
10	44.0	33.0	29.7	61.7	77.0	54.7	50.0
11	40.0	29.3	26.0	54.3	69.7	54.0	46.3
12	38.0	29.3	24.3	45.0	66.0	51.7	40.3
13	35.0	28.3	22.3	43.7	63.3	51.0	37.0
14	33.0	27.3	20.0	38.7	60.0	50.7	34.7
15	32.3	26.0	18.0	36.0	60.7	49.0	30.7
16	30.3	26.0	15.7	36.3	61.7	53.3	35.7
17	29.3	27.0	16.7	37.3	62.7	58.7	41.0
18	31.3	28.3	19.3	41.7	68.7	69.3	50.0
19	36.7	30.7	23.0	44.3	71.0	72.0	53.3
20	41.0	35.0	25.7	44.0	77.7	75.0	65.3
21	43.3	37.7	27.7	50.7	84.0	74.0	71.3
22	47.7	41.7	30.7	52.3	85.7	80.0	72.0
23	49.3	44.0	32.7	54.0	85.3	81.7	73.3
24	50.0	44.0	33.0	54.3	85.3	80.3	75.3

APPENDIX : 'A'

TABLE A.1

Hourly outdoor temperature (°C) for Kanpur from April to Octob[e]
taken as the average for three years, viz., 1982, 1983 and
1985

TIME	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
1.00	28.2	31.5	33.2	30.9	31.6	31.3	22.0
2.00	27.0	30.7	33.0	30.4	31.5	31.0	21.6
3.00	26.7	30.0	32.3	29.9	31.4	30.4	21.5
4.00	25.2	29.4	31.7	29.8	30.8	30.7	18.8
5.00	25.2	29.8	31.4	29.4	30.8	30.9	19.8
6.00	25.3	29.8	31.6	29.4	30.9	30.4	20.2
7.00	25.2	30.4	31.8	29.5	31.4	30.5	20.3
8.00	27.4	32.2	32.5	30.2	31.7	32.4	22.5
9.00	30.6	36.2	35.3	31.8	33.9	33.7	25.9
10.00	31.6	37.5	36.4	33.0	34.3	34.3	26.9
11.00	33.1	39.5	37.9	32.8	34.8	35.1	2[illegible].3
12.00	34.6	40.4	38.8	33.7	31.9	36.0	29.6
13.00	35.9	41.5	40.2	34.3	35.9	36.1	29.9
14.00	36.1	42.0	40.8	34.2	36.0	36.4	32.3
15.00	36.3	41.8	41.1	34.8	36.0	36.6	32.6
16.00	36.6	42.4	41.1	34.9	36.6	35.9	32.9
17.00	36.1	41.8	41.3	35.2	34.8	35.3	30.2
18.00	35.2	40.2	40.3	34.5	34.4	34.8	27.7
19.00	33.4	36.3	38.2	33.5	33.6	33.9	26.1
20.00	32.3	36.9	36.8	32.8	33.1	33.2	25.3
21.00	31.2	34.8	35.5	32.1	32.9	32.7	24.1
22.00	30.5	33.5	35.0	31.3	32.6	32.4	23.9
23.00	29.6	32.7	34.0	31.3	32.1	32.2	22.9
24.00	28.9	32.2	33.7	31.1	31.7	31.9	22.6

APPENDIX B

Type A: Tropical climate (temperature of the coldest month above 18 C)

Amw:

m - Short dry season exists, but is compensated by heavy rain during the rest of the year.

w - The dry season is during the winter.

As:

s - Dry season is high season period (May to September).

Aw:

w - Dry season is not compensated by rains during the rest of year. The dry season comes during low sun period of the hemisphere, viz., Sept. to May.

Type B : Represents dry climates.

BShw:

S - Semi-arid

h - Average annual temperature over 18 C

w - At least 70 percent of the rain falls in the summer six months.

BWhw:

W - Arid

h - same as in BShw

w - same as in BShw

Type C : Temperature of the coldest month below 18 C but above -3 C and the temperature of the warmest month above 10 C.

Cwg:

w - Dry season in winter; rainiest month of summer receives atleast ten times as much rain as the driest month of winter.

Type D : Temperature of the coldest month below -3 C and the temperature of the warmest month above 10 C.

Dfc:

f - No dry season, in the case of winter rain and summer drought, driest month receives more than 3 cm of rainfall.

Type E : Warmest month below 10 C

APPENDIX:C

Table C.1

Climatic conditions of some cities of India in January and the process required for comfort air conditioning

Place	Height from sea level (meter)	Average temperature (C)	Relative humidity (%)	Rainfall (cm)	Process required
Port Blair	79	26.35	70	2.89	A
Dibrugarh	106	16.25	87	3.49	H
Cherrapunji	1313	18.80	63	198.00	H
Calcutta	6	19.90	78	1.38	H
Patna	53	17.50	71	2.11	H
Kanpur	111	16.10	82	2.37	H
New Delhi	216	15.00	72	2.49	H
Dehradun	682	12.90	78	6.22	H
Dras	3066	-17.00	76	12.63	H
Jaipur	390	14.75	80	1.46	H
Jabalpur	393	17.45	60	1.40	H
Nagpur	310	19.65	74	2.64	H
Hyderabad	545	21.30	79	0.17	A
Bangalore	921	20.85	78	0.20	A
Bombay	11	24.55	71	0.01	A
Trivandrum	64	26.70	77	2.01	A
Madras	16	24.20	83	2.38	A

A – acceptable conditions
h – humidification required
C – cooling required
H – heating required
Dh– dehumidification required

<u>Table C.2</u>

Climatic conditions of some cities of India in May and the process required for comfort air conditioning

Place	Height from sea level (meters)	Average temperature (C)	Relative humidity (%)	Rainfall (cm)	Process required
Port Blair	79	28.10	77	36.25	C & Dh
Dibrugarh	106	26.55	82	36.63	C & Dh
Cherrapunji	1313	19.20	84	170.51	H & Dh
Calcutta	6	30.95	74	12.06	C & Dh
Patna	53	32.55	56	2.83	C & h
Kanpur	111	32.60	37	1.36	C & h
New Delhi	216	33.70	31	0.79	C & h
Dehradun	682	28.45	41	4.17	A
Dras	3066	8.50	68	6.40	H
Jaipur	390	32.65	33	1.00	C & h
Jabalpur	393	32.85	27	1.50	C & h
Nagpur	310	34.50	34	0.99	C & h
Hyderabad	545	32.45	50	3.00	C & h
Bangalore	921	27.10	75	11.65	A
Bombay	11	29.70	72	1.60	C & Dh
Trivandrum	64	28.35	84	24.86	C & Dh
Madras	16	32.90	63	5.17	C

A – acceptable conditions
h – humidification required
C – cooling required

H – heating required
Dh– dehumidification required

Table C.3

Climatic conditions of some cities of India in July and the process required for comfort air conditioning

Place	Height from sea level (meters)	Average temperature (C)	Relative humidity (%)	Rainfall (cm)	Process required
Port Blair	79	26.40	84	43.55	C & Dh
Dibrugarh	106	28.85	88	51.65	C & Dh
Cherrapunji	1313	21.45	93	245.67	Dh
Calcutta	6	29.55	84	30.06	C & Dh
Patna	53	30.45	81	26.58	C & Dh
Kanpur	111	31.10	82	29.90	C & Dh
New Delhi	216	31.95	73	21.11	C & Dh
Dehradun	682	27.70	85	72.08	C & Dh
Dras	3066	17.10	65	1.35	H
Jaipur	390	31.20	75	19.32	C & Dh
Jabalpur	393	28.70	85	50.50	C & Dh
Nagpur	310	28.40	83	31.15	C & Dh
Hyderabad	545	27.50	83	16.50	C & Dh
Bangalore	92	24.15	86	11.66	A
Bombay	11	27.45	85	70.95	C & Dh
Trivandrum	64	26.45	89	21.54	Dh
Madras	16	30.50	65	8.35	C & Dh

A – acceptable conditions
h – humidification required
C – cooling required
H – heating required
Dh– dehumidification required

Table C.4

Climatic conditions of some cities of India in November and the processes required for comfort air conditioning

Place	Height from sea level (meters)	Average temperature (C)	Relative humidity (%)	Rainfall (cm)	Process required
Port Blair	79	26.50	76	20.84	A
Dibrugarh	106	21.40	80	2.73	A
Cherrapunji	1313	16.00	65	4.67	H
Calcutta	6	23.20	74	3.49	A
Patna	53	21.65	62	0.57	A
Kanpur	111	20.15	71	0.14	H
New Delhi	216	20.10	48	0.12	H
Dehradun	682	17.23	70	0.51	H
Dras	3066	-1.10	81	2.29	H
Jaipur	390	20.75	48	0.34	H
Jabalpur	393	19.70	68	1.67	H
Nagpur	310	22.55	59	0.87	A
Hyderabad	545	21.65	68	2.49	A
Bangalore	921	21.15	78	5.43	A
Bombay	11	27.70	73	2.06	A
Trivandrum	64	26.75	87	20.69	Dh
Madras	16	25.70	83	30.87	Dh

A - acceptable conditions
h - humidification required
C - cooling required
H - heating required
Dh- dehumidification required

APPENDIX: D

COST OF THE HYBRID SYSTEM

Cost of 1 ton window air conditioner = Rs. 15000/-

Less cost of finned air-cooled condenser = Rs. 800/-

Cost of air conditioner without condenser = Rs. 14200/-

Cost of evaporative condenser = Cost of iron frame +
cost of copper tubes +
cost of wire mesh +
cost of wood wool +
labour cost
= 100+500+25+25+150 = Rs. 800/-

Cost of water tank = Rs. 150/-

Cost of water pump = Rs. 400/-

Cost of additional duct and insulation = Rs. 250/-

Total cost of hybrid system = Rs.(14200+800+150+400+250)
= Rs. 15800/-

APPENDIX E

ESTIMATION OF TOTAL COST

The total cost of the unit shall be constituted by the sum of initial cost, running cost and maintenance cost.

$$C_T = C_I + C_M + C_E$$

where C_T is the total cost

C_I is the initial cost

C_M is the maintenance cost

C_E is the running cost

For the estimation of the running cost the primary factor to be considered is electricity cost. Keeping in view the variation in electricity cost, a futuristic statistical approach has been adopted for the sake of realistic estimation. The logistic curve recommended for this purpose is given by [2] as:

$$C_C = \frac{1.293}{0.97986 + \exp[-0.0.338(I+4)]} \text{ Rs./kWh}$$

The effective cost of electricity is given by :

$$C_E = \frac{\text{Power}}{L} \sum_{I=1}^{L} \frac{C_C}{(1+R) * I - 1} \qquad \text{Rs.}$$

The maintenance cost is taken to be 10% of the initial investment [21]. Hence

$$C_M = 0.1 * C_I * \frac{(1+R)^L - 1}{R * (1+R)^{L-1}} * \frac{1}{L} \quad \text{Rs.}$$

For system B, the initial cost is estimated by using the relation

$$C_{I_b} = [\, C_{I_a} + \frac{C_{I_D}}{(1+R)^{L_D - 1}} * \beta \,] * \frac{1}{L}$$

APPENDIX F

SPECIFICATIONS OF THE ROOM FOR COOLING LOAD CALCULATIONS

Room size : 4.24 X 4.24 X 4.30 = 77.3 m^2

Net thickness of the wall = 0.01 + 0.225 + 0.01

= 0.227 m

Net thickness of the room = 0.01 + 0.120 + 0.01

= 0.140 m

No. of windows :

On the Southern wall = 3

On the other walls = 0

Area of windows = 2.97 X 0.36 + 2(2.97 X 0.55)

= 4.3362 m^2

No. of doors :

On the Northern wall = 1

On the other wall = 0

No. of the occupants = 8

No. of fans = 1

No. of electric bulbs = 2

No. of tubelights = 4

Ratings :

Fan = 75 W

Bulb = 100 W

Tube-light = 40 W